United States
Department of
Agriculture

Forest Service

Forest Pest
Management

Davis, CA

FIFTH REPORT

NATIONAL SPRAY MODEL AND APPLICATION TECHNOLOGY STEERING COMMITTEE

FPM 94-15
September 1994

Pesticides used improperly can be injurious to human beings, animals, and plants. Follow the directions and heed all precautions on labels. Store pesticides in original containers under lock and key—out of the reach of children and animals—and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides where there is danger of drift when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment, if specified on the label.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

NOTE: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the U.S Environmental Protection Agency, consult your local forest pathologist, county agriculture agent, or State extension specialist to be sure the intended use is still registered.

FPM 94-15
September 1994

Fifth Report

National Spray Model and Application Technology Steering Committee

Prepared by:

John W. Barry
Chairperson

USDA Forest Service
Forest Pest Management
2121C Second Street
Davis, CA 95616
(916)551-1715
FAX (916)757-8383

CONTENTS

I. INTRODUCTION

The meeting was held at Kansas City, MO, June 22, 1994 in conjunction with the International Summer Meeting of the American Society of Agricultural Engineers (ASAE). The meeting call letter and agenda is in Appendix A. This scheduling provided for economies in travel as several members of the committee present papers at the meeting or otherwise attend the ASAE annual meeting on a regular basis.

A. Attendees

Jack Barry (Chair)	USDA, Forest Service Forest Pest Management	2121-C 2nd Street Davis, CA 95616 PH (916) 758-4600 FAX (916) 757-8383
Terry L. Biery	US Air Force Reserve	910 AG/DOS 3976 King Graves Rd. Youngstown-Warren Rgn-Arpt ARS, OH 44473-0910 PH (216) 392-1178 FAX (216) 392-1156
Fred Bouse	USDA-ARS	231 Scoates Hall TAMU College Station, TX 77843-2122 PH (409) 260-9364 FAX (409) 260-9367
Jon Bryant	Sandoz	1300 E. Touhy Ave Des Plaines, IL 60018 PH (708) 390-3717 FAX (708) 390-3941
Parshall Bush	Ag Ser Lab	110 Riverbend Rd Athens, GA 30605 PH (706) 542-9023 FAX (706) 542-1474
Bruce Grim	US Army Dugway Proving Ground	Joint Contact Point US Army STEDP-JCT Dugway Proving Ground Dugway, Utah 84022 PH (801) 831-3371 FAX (801) 831-2397

600218

Jim Hadfield	USDA, Forest Service Eastern Washington Forest Health Office	Forest Sciences Laboratory 1133 N. Western Ave Wenatchee, WA 98801 PH (509) 664-2777 FAX (509) 664-2701
Andrew Hewitt	Stewart Ag.	PO Box 509 Macon, MO 63552 PH (816) 762-4240 FAX (816) 762-4295
Kevin D. Howard	USDA-ARS	PO Box 36 Stoneville, MS 38776 PH (601) 686-5240 FAX (601) 686-5422
Ellis Huddleston	New Mexico State Univ.	Box 3BE Las Cruces, NM 88003 PH (505) 646-3934 FAX (505) 646-5975
I. W. Kirk	USDA-ARS	231 Scoates Hall TAMU College Station, TX 77843-2122 PH (409) 260-9364 FAX (409) 260-9367
Bob Mickle	Environment Canada	4905 Dufferin Street Downsview, Ontario, Canada M3H 5T4 PH (416) 739-4851 FAX (416) 739-5708
Karl Mierzejewski	Penn. State Univ.	Pesticide Research Lab University Park, PA 16802 PH (814) 865-1021 FAX (814) 863-4439
Dave Miller	Univ. of Connecticut	308 W.B. Young Building 1376 Storrs Road Storrs, CT 06268 PH (203) 486-2840 FAX (203) 486-2504
William E. Steinke	Univ. of CA	Bio & Ag Engineering Davis, CA 95616 PH (916) 752-1613 FAX (916) 752-2640

Milton Teske	Continuum Dynamics, Inc.	P.O. Box 3073 Princeton, NJ 08543 PH (609) 734-9282 FAX (609) 734-9286
Harold Thistle	Missoula Technology Development Center	Bldg #1 Ft. Missoula Missoula, MT 59801 PH (406) 329-3981 FAX (406) 329-3719
Dave Valcore	DOW/Elanco	9410 Zionsville Rd S. Campus Bldg. 304 Indianapolis, IN 46268 PH (317) 332-7933 FAX (317) 332-7933
Nicholas Woods	Univ. of Queensland	C-PAS, Gatton College LAWES, QAD, 4343 Australia PH +61 74 601293 FAX +61 74 601283

B. Purpose of Committee/Meeting

The purpose of the committee is:

1. To exchange national and international information on spray model and application technology development activities;

2. To facilitate cooperation, partnerships, and economies;

3. To develop and maintain a 5-year tactical plan of goals, objectives and planned actions;

4. To identify model and application technology needs; and

5. To support the advancement of technology for the safe, economic, efficacious application of biorational and other pesticides.

The purpose of the meeting was:

1. To share information on development activities among the committee members and guests;

2. To encourage formation of partnerships; and

3. To identify spray model and pesticide application technology development needs.

II. DISCUSSION

The discussion as presented herein is a summary of remarks by attendees and/or a summary of their work. Some attendees provided a more detailed summary which is enclosed in the Appendices. My apologies if I missed some of your pertinent remarks.

A. Attendees Remarks and Reports

Dave Valcore

- See report in Appendix C.
- SDTF has field tested 30 different nozzles and 180 substances. These were aerial spray trials. There were 45 treatments and two replications.
- Mass balance recoveries observed were typically 90%.
- Inhalation air samplers were included.
- Big drift problem with ULV, 1-2 quarts per acre using 8002 & 8003 nozzles.
- As part of field studies, looked at drift vs nozzle types.
- Conducted 30 airblast sprayer trials comparing effects of orchard canopies.
- Have some data on drift in almond orchards.
- There will be some immediate label changes by EPA for some aerial applications to protect non-target endangered species, and buffer zones will be extended.
- Did work on collector efficiency at Battelle PNL. A white paper will be forthcoming.
- Battelle has published paper on air monitor collector efficiency.
- There are 31 members of SDTF.

Fred Bouse

- See report in Appendix C.
- Developed a leaf washer for removing chemicals for assay.

- CP 90 nozzles good for white fly control, small drops, high density. Also used aircraft winglets. Five gpa gave as good control as 10 gpa due to smaller drops.

- Evaluating electrostatic spraying of cotton, dual polarity is really helping.

- Doing drift reduction studies with Mylar collector, cotton string, and WS paper.

- Observed increased spray deposit on cotton with lower air speed. Flat fan nozzle gave more deposit on underside of cotton leaves. More drift with whirljet nozzle. Less drift at lower speeds - 120 mph vs 150 mph, 40 degree cone used, 65 degree might be ok.

- Need to look at ways to keep aircraft speeds up and still get penetration and reduce drift.

<u>Buddy Kirk</u>

- See report in Appendix C.

- Discussed dual side leaf washer.

- In canopy studies use 1x3 yellow water sensitive cards attached to both sides of leaf.

- Has a lot of canopy data that can be incorporated in model.

- Need to develop a crop canopy model in FSCBG.

<u>Bob Mickle</u>

- See report in Appendix C.

- Canada has an interdepartmental task force on spray drift and modeling.

- Canada has a large database on drift deposit associated with aerial application to forests that's available for others to use.

- Canada is validating spray drift models and will select one for regulatory use. Issue is the cut-off or threshold, what amount of drift is no longer significant? Will produce buffer zone graphs with model and compare to field trials.

- Chris Riley is evaluating models for Canada.

- Canada is testing models to be used operationally and will be adding input from differential GPS. Will require models that accept non-parallel spray lines.

- Aircraft guidance has been a big help to aerial application by reducing spray gaps. They use the AG/NAV navigation system.

- There is a difference in movement and deposit of spray from right wing vs left wing. He has published on this. Does FSCBG consider this difference?

- The effectiveness of forest buffers in protecting, aquatic systems still remains of scientific interest. It has potential to reduce size of buffers around water courses.

<u>Terry Biery</u>

- See report in Appendix C.

- Have 6 aerial spray systems and 5 each C-130E for spraying. Capacity of spraying a few ounces to large volumes.

- USAF conducts operational drift spraying with C-130E to control vectors - Bt and oil-based chemical pesticides are used. Some herbicide is sprayed.

- Involved in oil spill aerial spray technology.

- Conduct a pesticide certification course which is open to non-DOD personnel. Forest Service has helped with course.

- Dan Haile, USDA-ARS, is developing an expert system for mosquito spraying for USAF.

<u>Bruce Grim</u>

- See Rafferty report in Appendix C.

- US Army Dugway Proving Ground has working with the USDA Forest Service in studying spray drift, canopy penetration, helicopter sidewash.

- Supported canopy and drift studies for Forest Service in Utah during the 1991-1993 gypsy moth eradication program.

Parshall Bush

- See report in Appendix C.

- Has been conducting pesticide fate studies and has found that FSCBG prediction correlate well with field data.

Bill Steinke

- Conducting wind tunnel study to compare results of Malvern to PMS.

- Has a report he authored for Forest Service titled "Analysis of the USDA Forest Service 1988 Aircraft Spray Characterizations Trials" (FPM 93-5). Conclusions are:

    1. Sampling cards should be placed on the ground surface for the highest probability of measuring a positive swath width.

    2. Elevated cards tended to show zero swath widths more frequently, and also showed lower deposition in droplets/cm^2, and higher values for coefficient of variation within the swath width.

    3. Cards placed on the sides of stakes also give less consistent results.

    4. In order to capture all deposits, the perpendicular cardline should be extended laterally for field characterization. The exact length should be on the order of 200 meters (656 ft). Card spacing could be increased to 4 meters on the sample line, and still not increase the number of cards or readings over the trials.

    5. Swath width and mean deposition (drops/cm^2) as measured with ground cards, are essentially independent of wind speed.

    6. The most uniform pattern, in terms of droplets/cm^2, occurred just above the threshold of 10 droplets/cm^2 chosen for inclusion in the swath width.

- Working on an atomization scaling problem.

Harold Thistle

- Participated in FSCBG workshop in New Zealand.

- Developing partnerships with Forest Research Institute, New Zealand for studies of ground sprayers, tree barrier drift control, and spray meteorology.

- Will conduct spray aircraft navigation/GPS demonstrations in Montana during October 1994.

- Valdrift model that predicts drift in complex terrain has been developed with Battelle.

- Conducting training sessions on spray meteorology and modeling at the NAAA annual meeting in Reno, at the USAF certification course in Youngstown and at the FS PUMC course at Marana, AZ.

- Deployed meteorological instrumentation in support of deposition studies related to Peach twig borer suppression in Sacramento, CA.

- Presented papers on modeling of spray drift at the International Symposium on Pesticide Application Techniques in Strasbourg, FR and at the Society of Environmetal Toxicology and Chemistry annual meeting in Houston.

- MTDC is performing related pesticide application equipment development in the areas of ground burners for insect control in the litter, delivery systems for pheromones, stationary single tree sprayer systems and stump applicator saw heads.

- MTDC has completed a reported which is in press on a survey of block marking techniques for aerial spraying in the FS.

- Initiated effort to review and improve on existing approaches to canopy penetration of aerially released material (preliminary review paper presented at ASAE session in conjunction with committee meeting).

Milt Teske

- See report in Appendix C.

- AGISP has 42 in user group and FSCBG has 89.

- Has several FSCBG tasks under Forest Service contract.

Participated in [illegible] workshop in New Zealand.

Developing parameters [illegible] with Forest [illegible] [illegible], Tom [illegible] [illegible] [illegible] [illegible]

Will [illegible] spray aircraft, [illegible] demonstrations in [illegible] during October 19[illegible].

[illegible] model [illegible] reduces drift in southern forests has been developed [illegible]

[illegible] sprays, deposition, and modeling at the [illegible] in Reno, at the USFS [illegible] in Youngstown and at the [illegible]

Deployed meteorological instrumentation in [illegible]

Presented paper on modeling of [illegible] at the International [illegible] in Strasbourg, [illegible] and at the Society of Environmental Toxicology and Chemistry annual meeting in Houston.

MTDC is [illegible] related [illegible] equipment development in the area of ground [illegible] for insect control [illegible] systems for pheromones, [illegible]

MTDC has completed a report which is [illegible] a survey of [illegible] aerial spraying [illegible]

Initiated [illegible] comparison [illegible] material [illegible]

[illegible]

Ellis Huddleston

- Has contract/grant with EPA to study drift.
- Is conducting adjuvant/atomization in wind tunnel.
- Cooperating with Bill Steinke in comparing data from Malvern and PMS.

Jim Hadfield

- See report in Appendix C.
- Has planned and conducted operational aerial spray programs totally over 1 million acres.
- See his needs list in the Appendix.
- Forest Service has developed a field organization to conduct spray projects based upon the emergency fire suppression organization.
- Dramatic change in FS - reasons for spraying is becoming more for non-timber value reasons. As an example been asked to spray areas to protect spotted owl habitat.
- Concern about erratic spray results. Thinks it's pilot. They need experienced and better skills.

Jack Barry

- New contract with Continuum Dynamics, Inc. for FSCBG model work and technology transfer began 20 December 1993.
- In addition to New Zealand and Canada, Chile and Tasmania forest researchers have an interest in FSCBG as a management tool to meet efficacy and environmental objectives.
- Working with Frank Zalom, Director of California State-Wide IPM Program, to develop strategies for aerial spraying of Bt to control almond pests.
- Plan to conduct a "time-of-day" study to look at effects of temperature and radiation on drift, deposition, and total accountancy in near and far field.

- Evaluating feasibility of constructing a drop tower at Davis, CA for drop size and efficacy testing.

- Pest control in urban forests is a developing issue - how can it be done safely with public support?

- Non-target effects of Bt is a major issue in forest pest management.

- Cooperative Research - A Viewpoint

  One of the President's environmental goals is to reduce pesticide use. Improved application efficiency is one approach. I believe the USDA is well positioned to provide the leadership and to meet this challenge. This national steering committee could develop recommendations that would lead to a coordinated national application technology development program. The program could focus on developing technology that supports safe and efficient application and transfer this technology to the user. Such work is on-going but under funded and not coordinated.

  Both forestry and agriculture share the responsibility of reducing the pesticide burden in the environment. This provides an opportunity for both communities to work together and to share technology with the immediate objective to reduce the pesticide burden.

  An administrative approach would be to enhance this steering committee with scientists from other agencies. Canada would be an important partner on the proposed committee. The steering committee's charge would be to evaluate opportunities and mechanisms, and to develop a strategic plan that would lead to a well coordinated USDA pesticide application technology research program.

  The National Spray Model and Application Technology Steering Committee could provide the coordination of a USDA, EPA, and industry effort.

B. Sub-Committee on Meteorology

(See report - Appendix D.)

C. Sub-Committee on Models in the Regulatory Process -
Dave Valcore reporting

- EPA, USDA-ARS, and SDTF have signed an agreement for cooperative research on atomization and drift deposition and model developments.

- SDTF is adapting models for both aerial and ground spraying. DOW ELANCO model may be used for the simpler Tier 1 needs, AGDISP for Tier 2, and AGDISP/FSCBG for Tier 3.

- Will attempt to develop an orchard spray model.

- Model process is behind schedule - need to deliver Tier 1 model to EPA by end of 1994, final by end 1996.

- SDTF plans to deliver atomization model to EPA - 1st Qtr 1995. They will report on it at the 1994 Altanta ASAE meeting.

- SDTF and EPA might access to FS raw drift data (Note- most FS data has been reported or published but not raw data.)

- SDTF data that validated model is proprietory showing excellent agreement.

- For long-range drift predictions need to input 64 drop size categories.

- EPA wants the model to run in 5 minutes.

- Encourage USDA and ASAE on nozzle testing and standards.

III. RECOMMENDATIONS

The Committee reaffirmed needs that were identified for FY 1994. These are as listed:

1. Pursue development of expert systems as extension to FSCBG model for dose/biological response, non-target effects, environmental fate, and spray accountancy.

2. Link GPS on-board aircraft system inter-actively to FSCBG for real-time decision making, tracking, accounting, and documentation. Provide for direct data input to FSCBG from aircraft spray monitors with FSCBG being capable of modeling each spray line separately.

3. Pursue model development, enhancement, and technology transfer of FSCBG, with particular emphasis on simplicity and speed of operation, and extension of features suggested by national and international user group members. Continue information exchange at technical meetings and in peer-reviewed journals, and user group activities, including training sessions, newsletters, and model updates and improvements. Form partnerships with other US agencies and international cooperators to pursue application needs.

[illegible] be a [illegible] model for both vertical and lateral movement [illegible] [illegible] model by [illegible] for [illegible] Tier 1 models, [illegible] for Tier 2, and [illegible] for Tier 3.

Will attempt to develop an [illegible] model.

Model process is behind schedule - need to deliver Tier 1 model to [illegible] by end of [illegible], [illegible] by end [illegible].

[illegible] plans to deliver [illegible] model to EPA - [illegible] Oct. 1993. They will report on it at the [illegible] ASAE meeting.

[illegible] and [illegible] [illegible] [illegible] [illegible] in [illegible] drift data [illegible] [illegible] been [illegible] [illegible] but not [illegible] [illegible]

[illegible] data that validated model is [illegible] [illegible] [illegible] [illegible] [illegible].

For [illegible] drift predictions need to [illegible] [illegible] [illegible] [illegible].

[illegible] [illegible] the model, to run [illegible] 5 minutes.

[illegible] [illegible] and ASAE on [illegible] [illegible] [illegible] [illegible].

III. RECOMMENDATIONS

The [illegible] [illegible] recommendations were identified [illegible] 1991. They are as follows:

1. [illegible] development of [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] drift, [illegible] [illegible], [illegible], [illegible] [illegible] and [illegible] [illegible].

[illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible], and [illegible] [illegible]. [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]

[illegible] [illegible]

4. Cooperate with the industry-based Spray Drift Task Force and work with New Zealand to conduct field characterization and drift tests of orchard airblast sprayers, and implement a validated model into FSCBG directed toward supporting safe and economical use of insecticides and forest resource protection.

5. Evaluate and demonstrate the potential of tree or shelter belts for reducing spray drift and implementing findings into the FSCBG spray model.

6. Prepare a "hint book" and supporting documentation to provide guidance in collecting field data and to enhance the practical application of FSCBG. This effort would encompass guidelines for sampling, meteorological instrumentation, data collection, quality control techniques.

7. Evaluate the VALDRIFT complex terrain drift model with existing complex terrain field data to determine the influence of complex terrain on model predictions, and provide guidelines for future field studies and spray operations in complex terrain.

These were reported to Washington Office via letter on August 5, 1994 (Appendix B).

IV. SUMMARY

The Fifth Meeting of the National Spray Model Steering Committee was held at Kansas City, MO, on June 22, 1994. The committee reported on field testing and projects over the past year and discussed technology development needs concerning application technology and modeling drift, spray behavior, and environmental accountancy. The committee reaffirmed need to address the technical needs identified by the committee at the 1993 meeting. Again this year the committee noted the support of management in encouraging and funding projects through technology development and other sources; and the progress that has been made in advancing the models over the past year. The participation and other support of our colleagues in industries, academia, and other agencies are recognized and appreciated, for without their involvement the utility of this committee would be weakened. It is the chair's vision and I hope that of the membership that this committee might serve an increasing role of coordinating application technology research and development. My personal thanks to each of you in helping to develop, enhance, and transfer this technology. Our next meeting will be held at Chicago, IL the week of June 18-23, 1995 during the International Meeting of the American Society of Agricultural Engineers. Please mark your calendar as we are looking forward to your continued support and participation.

Appendices

Appendix A

Meeting Call Letter/Agenda

United States Department of Agriculture
Forest Service
Washington Office
2121 C Second Street
Davis, CA 95616
PH (916) 551-1715
FAX (916) 757-8383

Reply To: 2150

Date: May 6, 1994

Subject: Spray Model Committee Meeting - Kansas City

To: Members

The next meeting of the National Spray Model and Application Technology Steering Committee will be held Wednesday, June 22, 1994, at Kansas City, MO. The meeting has been scheduled in conjunction with the International Meeting of the American Society of Agricultural Engineers (ASAE). I know that several of you plan on attending the ASAE meeting to present papers and to participate in the PM-41 (Pest Control and Fertilization Sub-Committee) session "Canopy Penetration and Deposition." The PM-41 session is scheduled for Wednesday morning. Enclosure 1 is a list of papers that will be presented at this session.

The ASAE housing form (enclosure 2) is provided in case you want to request hotel reservations from the Westin (816) 474-4400, or Hyatt (816) 421-1234. Please note that the hotels are requesting reservations by May 19.

Judy Brown, ASAE headquarters, has assigned us the Roanoke Room, Westin Hotel, for our meeting. The meeting will begin on Wednesday at 1:00 pm and end at 6:00 pm. I have requested both an overhead and 35mm slide projector. Our thanks to Judy for her help again this year.

Our annual meeting provides an opportunity to review past year activities and results, discuss model applications, identify development needs, and share information. As in previous years you are encouraged to discuss your current research and other field research, and discuss your needs with the committee. We should plan talks/briefs not to exceed 15 minutes. I want to point out that the committee's charter includes, as an inherent part of spray model development, pesticide application technology. For this reason I have added application technology to the committee name. On the agenda (enclosure 3) you will note that I have included a 5-year tactical plan item. My intent is to begin developing a 5-year plan that will lead us to where the USDA Forest Service and its cooperators would like the models and application technology development to be in 5 years. We should allow time after member reporting to identify tactical plan goals.

I have also enclosed (enclosure 4) the 1993 list of pesticide application technology needs that the committee developed at the last meeting. You will also find a list of application needs (enclosure 5) as submitted by Jim Hadfield. The USDA Forest Service uses the recommendations generated by this committee to assist in allocating technology development funds. Likewise other

organizations should find the recommendations helpful in pursuing R&D programs. Please remember to bring a copy of your report to the committee and publications for sharing with the committee. The former will be added to this committee's 1994 report. I join you in looking forward to another informative meeting. See you in Kansas City.

John W. Barry

JOHN W. BARRY
Chairperson

Enclosures
1. Program, PM-41 canopy session
2. Hotel reservation form
3. Draft agenda
4. Model/application needs (1993)
5. J. Hadfield opn. needs

cc: Judy Brown, ASAE

Draft
5 May 94

AGENDA

NATIONAL SPRAY MODEL AND APPLICATION TECHNOLOGY
STEERING COMMITTEE

Westin Hotel, Roanoke Room, Kansas City, MO
22 June 94

Time	Topic	Discussant
1300	**INTRODUCTION**	Jack Barry
	Introductions Announcements Model newsletter Committee charter Purpose of meeting Expectations	
	SPOKANE (1993) MEETING	Jack Barry
	Recommendations Summary of follow-up activities	
	SUB-COMMITTEE REPORTS	
	Meteorology	Harold Thistle
	VALDRIFT Met guidelines for modeling document	
	Models in the regulatory process SDTF	Dave Valcore
	MEMBER REPORTS	
	Bob Mickle - Canadian Atmospheric Environment Service Model selections	
	Terry Biery - US Air Force Operational needs	
	Bruce Grim - US Army	
	Dave Valcore - SDTF update	
	Fred Bouse - USDA - ARS	

Bill Steinke - Univ. of California
- Scaling & atomization

Harold Thistle - USDA Forest Service (MTDC)
- New Zealand cooperation
- GIS/GPS/Aircraft Navigation
- Pheromone application

Milt Teske - Continuum Dynamics
- FSCBG 4.3 capabilities
- FSCBG New Zealand workshop
- Technology transfer (Canada, etc)
- Evaporation codes
- Atomization model
- Gypses Expert System
- SDTF interactions

Win McLane - USDA - APHIS

Parshall Bush - Univ. of Georgia
- FSCBG fate prediction studies

Ellis Huddleston - NM State University
- Application Technology Center

Temple Bowen - NOVO
- Operational gypsy moth programs

Dave Miller - Univ. of Connecticut
- Canopy/LIDAR visualization

Karl Mierzejewski - Penn. State Univ.
- FSCBG in prediction of ULV malathion drift in cotton

Jim Hadfield - USDA Forest Service
- Operational needs (see enclosure)

Others (Sorry if I missed your name)

Jack Barry - USDA Forest Service (WO/FPM)
- National training programs
- Biorational agent symposium
- ULV/Bt California orchards
- Urban forestry

1700 **Five-Year Tactical Plan** — Jack Barry
- Identification of goals

1745 CLOSING
- Follow-up Actions
- Next Meeting

Appendix B

Priorities - 1995 Technology Development Program

United States Department of Agriculture
Forest Service
Washington Office
2121 C Second Street
Davis, CA 95616
PH (916) 551-1715
FAX (916) 757-8383

Reply To: 2150

Date: August 5, 1994

Subject: Priorities - 1995 Technology Development Program

To: Acting Director, FPM

The National Spray Model and Application Technology Steering Committee met at Kansas City, MO on June 23, 1994, in conjunction with the International Meeting of the American Society of Agricultural Engineers. The purpose of the meeting was for the attendees from Federal government, States, academia, and industry to share information concerning their activities involving pesticide application technology and spray modeling; and to coordinate technology development needs.

The Committee reaffirmed needs that were identified for FY 1994. These are as listed:

1. Pursue development of expert systems as extension to FSCBG model for dose/biological response, non-target effects, environmental fate, and spray accountancy.

2. Link GPS on-board aircraft system inter-actively to FSCBG for real-time decision making, tracking, accounting, and documentation. Provide for direct data input to FSCBG from aircraft spray monitors with FSCBG being capable of modeling each spray line separately.

3. Pursue model development, enhancement, and technology transfer of FSCBG, with particular emphasis on simplicity and speed of operation, and extension of features suggested by national and international user group members. Continue information exchange at technical meetings and in peer-reviewed journals, and user group activities, including training sessions, newsletters, and model updates and improvements. Form partnerships with other US agencies and international cooperators to pursue application needs.

4. Cooperate with the industry-based Spray Drift Task Force and work with New Zealand to conduct field characterization and drift tests of orchard airblast sprayers, and implement a validated model into FSCBG directed toward supporting safe and economical use of insecticides and forest resource protection.

5. Evaluate and demonstrate the potential of tree or shelter belts for reducing spray drift and implementing findings into the FSCBG spray model.

6. Prepare a "hint book" and supporting documentation to provide guidance in collecting field data and to enhance the practical application of FSCBG. This effort would encompass guidelines for sampling, meteorological instrumentation, data collection, quality control techniques.

7. Evaluate the VALDRIFT complex terrain drift model with existing complex terrain field data to determine the influence of complex terrain on model predictions, and provide guidelines for future field studies and spray operations in complex terrain.

/s/John W. Barry
JOHN W. BARRY
Chair

cc: Forest Service Committee Members
J. Cota

Appendix C

Member Reports

Dave Valcore
SDTF

Fred Bouse
USDA-ARS

Ivan "Buddy" Kirk
USDA-ARS

Bob Mickle
Atmospheric Environment
Services - Canada

Terry Biery
USAF Reserve

Jim Rafferty
US Army Dugway Proving
Ground

Parshall Bush
University of Georgia

Milt Teske
Continuum Dynamics, Inc.

Jim Hadfield
R-6

Karl Mierzejeski
Pennsylvania State
University

Brian Richardson
Forest Research Institute
New Zealand

Nick Woods
The Center for Pesticide
Application and Safety

Dave Valcore
SDTF

SPRAY DRIFT TASK FORCE

PROGRESS REPORT

JUNE, 1994

by DAVE VALCORE

Atomiz. sub comm. Chrm

CONTRIBUTORS :

31 MEMBER COMPANIES

ATOMIZATION STUDIES

TESTED OVER 180 TEST SUBSTANCES

  * OVER 40 ACTIVE FORMULATIONS

USING NEARLY 30 DIFFERENT NOZZLES

NEARLY 2000 ATOMIZATON TESTS

SDTF ACTIVITY UPDATE SUMMARY

FIELD TESTING: AERIAL & GROUND FALL 93
ORCHARDS FALL '93 WINTER 94
Survey

STUDY REPORTS

C.R.A.D.A. - FORMAL SIGNING
EPA ORD ATHENS - EPA AREAL (RTP) - SDTF - USDA (ARS)
MODEL COMPARISON, TESTING & DEVELOPMENT

ATOMIZATION MODELING
A. I. ATOMIZATION Study

PHYSICAL PROPERTY METHODOLOGY & TESTING
DYNAMIC SURF.TENSION, EXTEN. VISCOSITY
EVAPORATION RATE

INTERACTIONS WITH EPA
(New Paradigm)

IMPACT
Labels, Product Chem.

WHITE PAPERS

AERIAL SUMMARY

- 180 Applications
  - 45 Treatments
  - 2 Replications
  - 2 Treatment Types (Standard and Variable)
- Wind Speeds of 2 to 16 mph
- Temperatures of 32 to 95°F
- Relative Humidities of 7 to 94%

AERIAL STUDIES

<u>Variables Covered:</u>

Climate -	hot, dry; hot, humid, cool
Release height -	7-25 ft
Boom length -	67-85% of wing span
Canopy -	cotton
Stable air	(temperature inversion)
ULV oil -	1 and 2 qt/A
Droplet sizes -	118 to 546 VMD
Aircraft speed -	60 to 150 mph
Gallonage rates -	0.25 to 8 gpa

Full field

Differing physical properties

Full rates of formulated product

GROUND SUMMARY

- **48 Applications**
  - **12 Treatments**
  - **2 Replications**
  - **2 Treatment Types (Standard and Variable)**
- **Wind Speeds of 5 to 20 mph**
- **Temperatures of 44 to 92°F**
- **Relative Humidities of 8 to 82%**

NOZZLES USED IN GROUND STUDIES

Nozzle	Use	Approximate VMD (μm)
8010LP	Right-of-way Worst case residential	750
8004LP	Agricultural	340-480
8004	Agricultural	340-480
TX6	Crop canopies Low gallonage	170

AIRBLAST SUMMARY

- 33 Applications
  - 6 Orchard/Sprayer Scenarios
  - 3 Treatments
  - 2 Replications
- Wind Speeds of 3 to 10 mph

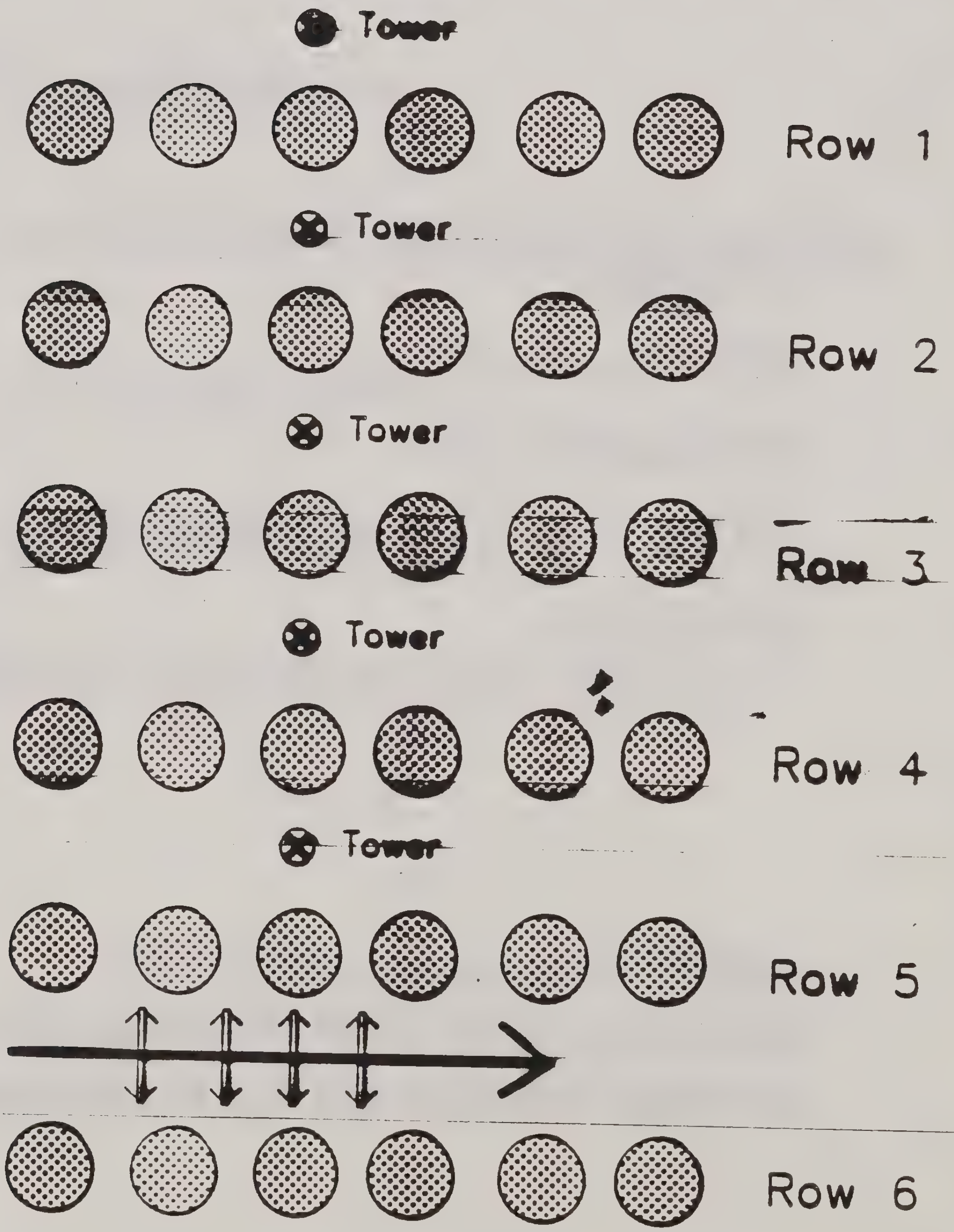
Additives Used in Physical Property, Droplet Evaporation Studies and Atomization Studies

- Staput
- Ortho X-77
- Silwet L-77
- Crop Oil Concentrate
- Induce

Additives were mixed at various concentrations with several pesticide formulations.

FIELD DESIGN

Modeling Treatment



C.R.A.D.A.

COOPERATIVE RESEARCH & DEVELOPMENT AGREEMENT

SDTF - EPA O.R.D. ATHENS & AREAL Lab., - USDA - ARS

FOR JOINT DRIFT MODELING DEVELOPMENT & TESTING & DATABASE DEVELOPMENT.

- Aerial Model Comparisons DESDM Vs USFS AGDISP (FSCBG) both giving $R^2 > 0.9$

Orchard Airblast Model Development

USDA ARS - Committed a man-year for model evaluation, field testing, drift mitigation testing.

Data and Model Development with Canada & possibly Europe.

Fred Bouse
USDA-ARS

JUL 5 1994

United States Department of Agriculture

Agricultural Research Service

Southern Plains Area
Southern Crops Research Laboratory
Aerial Application Research Unit
231 Scoates Hall, TAMU
College Station, TX 77843-2122
409/260-9364 FAX: 409/260-9367

June 27, 1994

John W. Barry
USDA-FS
2121 C Second Street
Davis, CA 95616

Dear Jack:

I am enclosing a summary statement of my report for the minutes of the Spray Modeling and Application Technology Meeting. This report closely resembles an abstract that we prepared for the IPM Symposium earlier this year. I hope it is sufficient.

Sincerely,

FRED

L. F. Bouse
Agricultural Engineer

Enclosure:

cc: I.W. Kirk

IMPROVED DELIVERY SYSTEMS FOR INCREASED EFFICACY AND SAFETY IN AERIAL SPRAY APPLICATIONS. L.F. Bouse, J.B. Carlton, E. Franz, I.W. Kirk, and M.A. Latheef, Aerial Application Research Unit, USDA-ARS, 231 Scoates Hall, TAMU, College Station, TX 77843

Develpoment of improved technology for depositing a lethal dose of pest control material on plant foliage while maintaining control of spray drift has been identified as a major thrust area by the Aerial Application Research Unit. Current technology is sometimes inadequate for depositing a lethal dose of spray material for control of pests such as aphids and whiteflies which reside on the underside of leaves deep within mature plant canopies. Unit scientists have determined the effects of several application variables on the deposition, drift, and efficacy of aerially-applied sprays. Constant temperature anemometry was used to measure the effects of aircraft loading, airspeed, and height of flight on aircraft wake intensity. Increasing aircraft loading, decreasing airspeed, and decreasing height of flight increased mean airflow and turbulence at the crop canopy. Winglets (air deflectors) attached to an aircraft spray boom also increased the initial downwash and air turbulence at the crop canopy. Studies in cotton (1991) and in cotton and cantaloupe (1992) showed that increased droplet size, downwash, and air turbulence resulted in increased total spray deposits on plants. Treatments with higher wake intensity increased deposits on the undersides of leaves, but deposits on the undersides of leaves were still small compared to those on the tops of leaves. A season-long study (1993) was conducted to compare the control of whitefly in cotton when using several aerial application systems, including rotary atomizers, winglets, trumpet nozzles, and CP nozzles. Results showed that none of the treatments were superior in delivering spray to target plants; however, treatments that deposited the smallest droplet spectrum gave the best season-long insect control. In a comparison of nozzle types and airspeeds to determine the effects on spray drift and on deposition on cotton leaves (1993), flat spray nozzles produced larger droplets and, in general, provided more spray deposit on both the tops and bottoms of leaves than whirl-type hollow cone nozzles. Spray drift at 140 m downwind was greater for the hollow cone nozzles and for the higher airspeeds. Results of these various studies have shown that aerial applicators can select equipment and operating parameters that increase spray deposition and efficacy while minimizing off target spray losses.

Ivan "Buddy" Kirk
USDA-ARS

United States Department of Agriculture

Agricultural Research Service

Southern Plains Area
Southern Crops Research Laboratory
Aerial Application Research Unit
231 Scoates TAMU
College Station, TX 77843-2122

JUL 5 1994

June 30, 1994

John W. Barry, Program Manager
U. S. Department of Agriculture
Forest Service
2121 C Second Street
Davis, CA 95616

Dear Jack:

A brief summary containing the gist of my thoughts presented at the National Spray Model and Application Technology Steering Committee meeting is enclosed as requested. We appreciate your and Milt Teske's interest in following through with incorporation of crop canopies into FSCBG/AGDISP.

I regret that Fred Bouse and I had to leave the meeting before it was over. Please let us know of items that transpired that we should be aware of or involved in. It was a good meeting; we appreciate the opportunity to be involved.

Sincerely,

Buddy

Ivan W. Kirk
Agricultural Engineer

PHONE: (409)260-9364 • FAX: (409)260-9367

Spray Deposition in Crop Canopies

ARS researchers at College Station, Texas, have conducted spray deposition studies in cotton (3), wheat (2), rice (1), and mesquite (2). These studies were conducted with primary objectives of determining the influence of spray rate and droplet size on active ingredient deposition in the top and bottom half of the plant canopy. Deposition was measured on mylar plates, soda straws, water sensitive paper (WSP), and plant leaves. Crop canopies were qualitatively characterized in the early studies; but we began efforts to better characterize canopy with manual and LAI-2000 measurements near the end of this series of studies. Damaging infestations of silverleaf whitefly in cotton and vegetable crops in 1991 prompted a redirection of efforts to optimize spray deposition on the underside of crop leaves deep in the crop canopy. Carlton's dual-side leaf washer was developed to facilitate measurement of spray deposits on the top and bottom surfaces of crop leaves. This technique plus WSP on top and bottom surfaces of leaves were used to characterize spray deposits at top and mid-canopy locations in studies on cotton (2) and cantaloupe (1). LAI-2000 was used to characterize the cotton canopies and manual measurements were made in both cotton and cantaloupe to further characterize the canopy. Another study was made in cotton where WSP and manual measurements were made to characterize spray deposits and crop canopy. Season-long whitefly efficacy data were also collected in this study. Beginning with our training on AGDISP in 1990, these studies had secondary objectives of obtaining data that would be useful in modeling spray deposition in crop canopies. Canopy characterization in AGDISP is primarily for trees; the data collected in the above-noted studies should provide a basis for incorporating smaller crop canopies into the model. We would be pleased to cooperate with modelers to that end.

Selected Recent Publications

Bouse, L. F. Effect of nozzle type and operation on spray droplet size. Am. Soc. Agric. Eng. Paper AA91-005. 1991.

Bouse, L. F., Whisenant, S. G. and Carlton, J. B. Aerial spray deposition on mesquite. Trans. ASAE 35(1):51-59. 1992.

Bouse, L. F., Carlton, J. B. and Kirk, I. W. Nozzle selection for optimizing deposition and minimizing drift for the AT-502 Air Tractor. Am. Soc. Agric. Eng. Paper AA93-006. 1993.

Carlton, J. B. Simple techniques for measuring spray deposit in the field II: Dual side leaf washer. Am. Soc. Agric. Engr. Paper 921618. 1992.

Kirk, I. W., Bouse, L. F., Carlton, J. B., Franz, E., and Stermer, R. A. Aerial Application Parameters Influence Spray Deposition in Cotton Canopies. American Society of Agricultural Engineers/National Agricultural Aviation Association, Paper No. AA91-007, Las Vegas, Nevada. Dec. 1991.

Kirk, I. W., Bouse, L. F., Carlton, J. B., Franz, E., Latheef, M. A., Wright, J. E., and Wolfenbarger, D. A. Within-Canopy Spray Distribution from Fixed-Wing Aircraft. American Society of Agricultural Engineers/National Agricultural Aviation Association, Paper No. AA92-005, Las Vegas, Nevada. Dec. 1992.

Kirk, I. W., Bouse, L. F., Carlton, J. B., Franz, E., and Stermer, R. A. Aerial Spray Deposition in Cotton. Transactions of the ASAE 35(5):1393-1399. 1992.

Kirk, I. W., Bouse, L. F., Carlton, J. B., and Latheef, M. A. Aerial sprays for control of sweetpotato whitefly in cotton: deposition. American Society of Agricultural Engineers/National Agricultural Aviation Association, Paper No. AA93-004, Las Vegas, Nevada. Dec. 1993.

Latheef, M. A., Bouse, L. F. and Kirk, I. W. Aerial sprays for control of sweetpotato whitefly in cotton: efficacy. Am. Soc. Agric. Eng. Paper AA93-005. 1993.

Whisenant, S.G., Bouse, L. F., Crane, R. A. and Bovey, R. W. Droplet size and spray volume effects on honey mesquite mortality with clopyralid. J. Range Management 46:257-261. 1993.

Bob Mickle
Atmospheric Environment
Services - Canada

29/06/94

ATMOSPHERIC ENVIRONMENT SERVICE
SERVICE DE L'ENVIRONNEMENT ATMOSPHÉRIQUE

AIR QUALITY RESEARCH BRANCH
DIRECTION DE LA RECHERCHE SUR LA QUALITÉ DE L'AIR

facsimile (416) 739-5708
telephone (416) 739-4841

4905 Dufferin Street
Downsview, Ontario M3H 5T4

To/A	**Jack Barry**
Department/ Company Ministere/ Compagnie	**USDA/FS**
Facsimile Telecopier	**916 757 8383**
Pages to follow Pages a suivre	2
From/De	Bob Mickle
Section	Physical Processes Section
Telephone	416 739 4851

Reference

Report from NSMAT Steering Committee meeting.

June 29, 1994

To: Jack Barry
USDA forest Service

From: Bob Mickle
AES

Re: **NSMAT Steering Committee Meeting, Kansas City**

Below is the information requested from the Kansas City

1) Strategy for Reducing Drift of Aerially Applied Pestici

A NRC report documenting the results from the field trial differences in the deposit and drift from the upwind and a spray aircraft is now available. The report documents seve of spraying in cross winds in stabilities ranging from sta Results have clearly demonstrated that deposits from the greater than from the down wind wing leading to a decrease mass in the drift cloud at 200m and 600m away from the number of copies are available by contacting Peggy McCoo 993-2521. It is tentatively being planned to present the re NAAA Meeting in Las Vegas.

2) Interdepartmental Task Force on Pesticide Drift

The contract to assess a number of spray models again base is nearing completion. A final report is due late models are being evaluated including FSCBG, AGDISP contract is assessing the sensitivity of the models following on from the work of Teske and Barry (1993). parameters to be investigated have encompassed the da for herbicide and insecticide applications to forests. will be evaluated on their performance in predicting following the generic technique of Mickle (ACS Meeting 1 buffer zones and assessing the potential for environ

3) Linking GPS to Model Predictions

Two experimental spray programs were completed this year with FPMI during which position of the aircraft was logged using differential GPS (AgNav Guidance System). The positional data complemented the onboard Aircraft Spray Monitor which recorded a number of other parameters relevant to the spray program including aircraft height, flows, boom pressure, rotary atomizer rpm, and met data at the aircraft height. Intensive deposit sampling within the canopy and on the ground was taken during these spray programs. The aircraft data are being used to produce contour diagrams of application rate from the aircraft as well as simulated deposit contours based upon swath characterization using the Swath Kit analyzer. The final step in this program will be the use of the data set to exercise the model for a semi-operational spray with non-parallel spray lines to predict the ultimate fate of the application. Initially, each spray line will constitute a separate run of FSCBG with accumulation of the deposit predictions. The results will be compared against the in-situ deposit measurements.

4) Recommendations for Enhancements to FSCBG

My recommendations remain basically the same as last year.

1> Allowance for direct data input to FSCBG from Aircraft Spray Monitors with FSCBG being capable of modelling each spray line (allowing for non-parallel lines and changes in both spray parameters (ie flow, height, etc) and met conditions).

2> Allowance for discrete changes in canopy down wind of the spray block to allow for assessment of treed buffers in protecting sensitive areas such as aquatic habitats.

3> Allowance for selective destruction of down wind vortex in cross wind spraying and hence impact on deposit and drift due to spray from each wing.

Terry Biery
USAF Reserve

22 June 1994 Steering Committee Meeting

USAFR Report by: Terry Biery

1. Our operational needs are:

   a. Using pre-spray weather about 1 hour prior to spray start to run model to:

      (1) Determine where we should get first downwind offset, deposition.

      (2) Determine buffer distance required to prevent downwind drift of environmental significance.

   b. To validate flux in model for our space spraying of vectors for control of diseases.

2. We have completed characterization studies for our C-130 Modular Aerial Spray System (MASS) with:

   a. <u>Btk</u> for gypsy moth control

   b. <u>Bti</u> for mosquito larvauding in flood areas

   c. Oil dispersant

3. Technology Transfer:

   a. We conducted a session on the model at our recently completed DoD Aerial Dispersal of Pesticide Certification Course.

      (1) Had 55 participants with USDA students from FS, APHIS, and ARS.

      (2) Student from Britian with their oil dispersant program who were very interested in applying the FSCBG model to their operations.

   b. We are developing an expert system for adult mosquito control in cooperation with Dr. Don Haile at the USDA ARS Medical and Veterinary Insect Laboratory, Gainesville, FL. We would like to use FSCBG in the expert system.

Jim Rafferty
US Army Dugway
Proving Ground

FSCBG ANALYSIS OF THE 1990 OREGON SEED ORCHARD TRIALS

BY JAMES RAFFERTY

OBJECTIVES:

1. EVALUATE FSCBG CANOPY PENETRATION MODEL PREDICTIONS VS FIELD TRIAL DATA FROM TWO DOUGLAS FIR SEED ORCHARDS IN OREGON

2. PROVIDE MODEL INPUTS FROM THE LAI-2000 PLANT CANOPY ANALIZER MEASUREMENTS FOR POSSIBLE INCLUSION IN AN FSCBG LIBRARY OF CANOPY INPUTS

SAMPLING PROCEDURES

* DEPOSIT CARDS IN PLASTIC HOLDERS WERE HAND COUNTED
* IRREGULAR GRID SPACING USED TO RANDOMIZE SAMPLES IN A REGULARLY SPACED FOREST
* FRACTION OF APPLIED DEPOSITION WAS CALCULATED: MEAN DEP/10 GAL/ACRE
* SEVEN CALIBRATION TRIALS USED TO CHARACTERIZE DROP DISTRIBUTION

Spraying Chronology.

Spray Block	Application 1		Application 2	
	Date (1990)	Time (PST)	Date (1990)	Time (PST)
Schroeder-Nehalem	4 April	0756	1 May	- -[a]
Schroeder-Vernonia	5 April	0740	2 May	- -[a]
Horning-Block 12	18 April	1237	9 May	0646
Horning-Block 14	12 April	0755	8 May	0732

[a] The time of spray was not recorded for these applications.

Sky Radiation Measurements.

Zenith Angle (deg)	Fraction of Above Canopy Radiation		
	Horning Block 12	Horning Block 14	Schroeder Nehalem
7	0.3207	0.3107	0.5856
23	0.2426	0.3452	0.5331
38	0.2274	0.2954	0.5029
53	0.1782	0.2476	0.4882
68	0.09275	0.1708	0.3453

FSCBG Calculated Canopy Penetration.

Orchard	Block	Application	Calculated Penetration Fraction	Predicted to Observed Ratio
Horning	B12	1st	0.304	0.429
		2nd	0.304	0.792
Horning	B14	1st	0.373	0.833
		2nd	0.374	0.712
Schroeder	Nehalem	1st	0.638	0.919
		2nd	0.638	0.825
Schroeder	Vernonia	1st	0.638	1.30
		2nd	0.638	2.02

RESULTS:

* FOR TWO TRIALS PREDICTION IS OFF BY A FACTOR OF 2
* REMAINING 6 TRIALS WITHIN 30% OF PREDICTION
* PREDICTED CANOPY PENETRATION RATIOS CORRESPOND WELL WITH LAI-2000 READINGS AT SMALL ZENITH ANGLE - - THIS RESULT WOULD BE EXPECTED FOR THE LOW WIND SPEEDS AND LARGE DROPLETS OF THESE TRIALS

CONCLUSIONS:

* RESULTS OF THESE TRIALS SHOW THAT THE USE OF RADIATION MEASUREMENTS IN DOUGLAS FIR CANOPIES SHOULD YIELD GOOD PREDICTIONS WHEN USING THE FSCBG CANOPY MODEL
* SINCE THIS CANOPY IS A SEED ORCHARD ARRANGED IN A GEOMETRIC PATTERN IT WILL NOT PROVIDE REPRESENTATIVE RADIATION INPUTS FOR NATURALLY OCCURING DOUGLAS FIR CANOPIES

Parshall Bush
University of Georgia

Paper No. 941030
An ASAE Meeting Presentation

FSCBG: A MANAGEMENT TOOL FOR AERIAL PESTICIDE APPLICATION

by

Parshall B. Bush
Sandra S. Chapman
USDA Cooperative Extension Service
University of Georgia
110 Riverbend Road
Athens, Georgia 30602

John W. Taylor
USDA Forest Service, R8
1720 Peachtree Road NW
Atlanta, Georgia 30367

John W. Barry
USDA Forest Service
Forest Pest Management
2121C Second Street, Suite 102
Davis, California 95616

Written for Presentation at the
1994 International Summer Meeting
Sponsored by
ASAE
Kansas City, Missouri USA
June 19-22, 1994

Summary:

Permethrin was aerially applied to five plots in coastal plain loblolly pine stands with varying canopy densities. The operational application of permethrin (Pounce®) was monitored to : (1) calibrate/validate the critical FSCBG parameter "probability of penetration" for loblolly pine stands by comparing measured and predicted ground deposition, and (2) evaluate management options for operational applications. The model closely predicted the measured deposition of permethrin. This study demonstrates that FSCBG is a useful tool for defining factors that influence pesticide deposition in operational spray.

Keywords:

FSCBG, aerial application, modeling, permethrin

INTRODUCTION

The increased frequency of aerial pesticide applications for insect control establishes the need for predicting pesticide ground deposition and drift, particularly when drift or off-site movement poses a threat to sensitive organisms in nearby aquatic habitats. This report is part of an on-going study using the Forest Service FSCBG computer model to predict pesticide deposition in loblolly pine (*Pinus sp.)* stands and develop monitoring programs for forest management purposes. Previous modeling efforts (Teske and Barry 1993; Bush et. al. 1993) indicate that the FSCBG input parameter, probability of penetration, is critical for acquiring accurate predictions of pesticide deposition from aerial application.

An aerial application of the pyrethroid permethrin was monitored to determine the probability of penetration factor. Permethrin is a broad spectrum insecticide widely used as a component in household, forest, farm, and ranch sprays. It is relatively non-toxic to birds and mammals. Permethrin is readily metabolized and excreted by most animals. No harmful effects of permethrin to birds or mammals in field or forest ecosystems have been reported (Berisford et. al. 1985). Acute oral LD_{50}s for small mammals range from 410-20,000 mg/kg depending on whether or not a carrier is used. In bird laboratory bioassays, LD_{50}s ranged from 4640-15,500 mg/kg. LC_{50}s for fish species range from 0.9-52.0 ug/l (Berisford et. al. 1985). Numerous laboratory studies suggest that permethrin is highly toxic to fish. However, research indicates that it is readily bound to suspended and sediment organic matter and is innocuous in most natural situations. Amphibians are not adversely affected in the natural environment when permethrin is used according to recommended rates and application procedures.

With the exception of water-grown duckweed, permethrin is not absorbed by plants. In general, deciduous tree leaves have higher initial residue levels per cm^2 than conifers following ULV aerial applications. However, the half-life of permethrin is approximately the same for both groups. When applied at to recommended field rates, permethrin has a half-life of 14 to 23 days on coniferous and deciduous forest trees. The general conclusion is that permethrin at 17.5 gm ai/ha has little or no long term effect on the forest environment (Berisford et. al. 1985).

Permethrin degrades slowly in water by chemical and photochemical pathways, but is rapidly metabolized by microbial populations present in natural waters. The half-life of permethrin in water is of the order of hours, but it is accumulated in sediments and may persist there for months (Berisford et. al. 1985). It is strongly absorbed to particulate matter in both water and soil. In soil, permethrin is essentially immobile, neither volatilizing into the air nor leaching downward in the soil profile with water. The half-life in soil is approximately 1 to 4 weeks, but varies depending on soil type and environmental conditions.

The objectives of this study were to:

1. Monitor operational permethrin (Pounce®) applications to five of loblolly pine stands with varying canopy densities.
2. Monitor operational permethrin application to determine:
    a. droplet size distribution
    b. effect of release height

3. Calibrate/validate the critical FSCBG parameter "probability of penetration" for loblolly pine stands by comparing measured permethrin deposition with simulated deposition.

PROCEDURE

Study Site

The study site was located on Union Camp Corporation Property in the Combahee Forest at Hamilton Ridge Circle in Hampton County, South Carolina (Figure 1). Five study plots (3.6 ha each) of loblolly pine (*Pinus sp.*) were selected during a preliminary visit to the Union Camp Property. Sites were selected based upon the height and density of the canopy. Canopy density varied from dense (little probability that a spray solution will pass through the canopy, Block 5) to open (no canopy to intercept the spray solution, Blocks 2 and 4. Two newly established seedling sites (Block 2 and 4; <25 cm height) were selected as bare soil sites. Block 1 and 3 were intermediate in number of stems/ha and canopy density.

Application Parameters

A single application of Permethrin (Pounce®) was aerially applied on 9 July, 1993 just above the canopy at the operational rate of 0.117 kg ai/ha (6.0 ounces/acre) by a Grumman Ag-Cat bi-plane. Each tank mix contained the following additives; 1.2 L of More, 0.6 L of Surfix, and 0.5% Rhodamine WT dye. Pounce® was applied over five 182.4 m X 182.4 m (600 ft. X 600 ft.) plots of loblolly pine (*Pinus sp.*) stands. The study blocks were part of a larger operational spray block. The center (60.8 m X 60.8 m) of each block was the designated sampling area to assure at least 60.8 m on all sides to minimize edge effects.

Verification of the aircraft swath width and calibration of equipment were made prior to the application (8 July, 1993). Keyacid® Rhodamine WT liquid dye (Keystone Aniline Corp.) was added to the aerial spray mixture for the application to aid in spray droplet characterization. The dye was intercepted on Kromekote® cards.

Sampling and Analysis

Fifty (per study plot) 9 cm diameter glass fiber disks were placed in numbered petri dishes. On the morning of the application, the petri dishes were opened to expose the glass fiber disks. Kromekote® cards (50) were paired with the glass fiber disks for spray droplet characterization. Petri dishes were re-covered after the permethrin application and placed in a cooler for transport to the laboratory.

The ground deposition disks were analyzed at Agricultural Services Laboratory Pesticide Lab, The University of Georgia, Athens, Georgia. The Kromekote cards were analyzed by the USDA Forest Service, Asheville, North Carolina. Initial ground deposition of permethrin was calculated from residues intercepted on the 9 cm diameter glass fiber disks. Spray droplet sizes were characterized by analysis of the Kromekote cards.

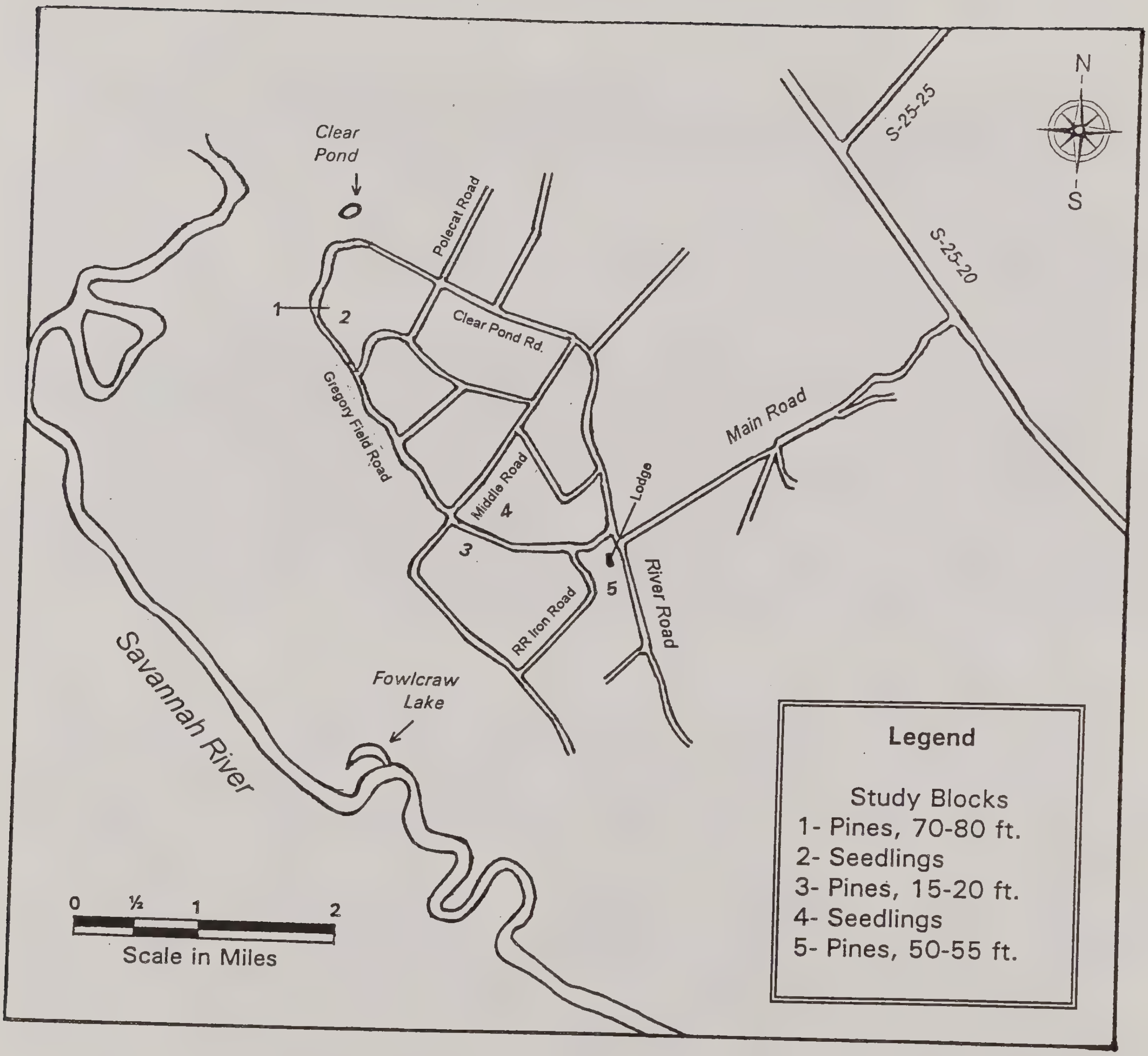


Figure 1. Map of study site.

Extraction and Quantitation

Each glass fiber disc was transferred to a 15 ml glass culture tube and 10 ml of trimethylpentane was added. The sample was shaken for 5-10 seconds and allowed to settle. Samples were sonicated in an ultrasonic bath for 15 minutes and aliquots were withdrawn for GC analysis. Quantitation of permethrin was conducted using a Tracor Model 222 gas chromatograph equipped with a Ni^{63} electron capture detector and a 2 M x 4 mm I.D. glass column packed with 3% OV-1 on Chromosorb WHP. The detector, inlet, and column temperatures were 350° C, 260° C, and 240° C, respectively. The carrier and purge gases were 5% methane/95% argon, with a flow rate of 45 ml/min. and 10 ml/min., respectively. Residue levels were determined by comparison of peak heights in sample chromatograms to those of analytical standards obtained from the Environmental Protection Agency Research Triangle Park, Raleigh, North Carolina. A reagent blank and spike sample were included in each set of analyses.

Analysis of Kromekote Cards

The spray droplets deposited on Kromekote® cards were analyzed with an image analyzer (Sanderson 1991). Spray droplet size and mass volume were calculated by the Automatic Spot Counting and Sizing Program (ASCAS version 4.0) program on a personal computer (Teske 1992).

Input Parameters for FSCBG Simulations

The current FSCBG Version 4.3 (1994) obtained from Continuum Dynamics, Inc., Princeton, New Jersey, was used for all simulations of permethrin ground deposition. Input parameters are listed in Table 1. FSCBG permits the selection of application parameters specific to the site and treatment involved; therefore canopy height, canopy density and stand density (stems per acre) were determined prior to the permethrin application. Meteorological characteristics were recorded on-site at the time of pesticide application.

Aircraft and equipment characteristics were obtained from the aircraft pilot and from FSCBG default values. The spray boom contained 47 CP nozzles (The CP Products Company, Inc., Mesa, Arizona) spaced 15 cm (6 inches) apart along the boom. The aircraft made 10 passes (flight lines) over each site, depositing the application solution at a rate of 47 L/ha with a swath width of 18.3 m. The spray volatile fraction (0.89) was inferred from the known amount of spray material added to the known amount of water. Meteorological characteristics (wind speed, wind direction, ambient temperature and relative humidity at 1 m height) were determined using hand held field equipment. The radiation index parameter was estimated as follows: dark to 8:00 am = +1.0; 8:00 am to 10:00 am = +2.0; 10:00 am to 12:00 = 3.0; 12:00 - 4:00 pm = +4.0.

Table 1. Summary of permethrin (Pounce®) application data on 9 July, 1993 for FSCBG simulations.

	APPLICATION SITES				
	BLOCK 1	BLOCK 2	BLOCK 3	BLOCK 4	BLOCK 5
Aircraft Speed	53.6 m/s	53.6 m/s	53.6 m/s	53.6 m/s	53.6 m/s
Permethrin Concentration in Spray Solution	2660 ppm	2660 ppm	2660 ppm	2660 ppm	2660 ppm
Spray Release Height	25.5 m (84 ft)	3.04 m (10 ft)	7.9 m (26 ft)	22.8 m (75 ft)	18.5 m (61 ft)
Rate (kg ai/ha)	0.117	0.117	0.117	0.117	0.117
Volatility	0.89	0.89	0.89	0.89	0.89
Hectares Treated	3.6	3.6	3.6	3.6	3.6
Stems per hectare	162	0	250	0	285
Tree Height	21.3 m (70 ft)	0	5.3 m (17 ft)	0	15.8 m (52 ft)
Temperature(°C)	38	33	38	30	38
Relative Humidity	83%	83%	83%	82%	83%
Wind Speed	1.7 m/s (3.8 mph)	1.2 m/s (2.7 mph)	2.0 m/s (4.5 mph)	1.2 m/s (2.7 mph)	2.0 m/s (4.5 mph)
Wind Direction	310°	310°	310°	190°	310°
Radiation Index	4.0	3.0	4.0	2.0	4.0
Approximate Time of Application	12:30 pm	10:45 am	12:45 pm	10:00 am	1:00 pm

Table 2. Theoretical droplet diameter compared to measured deposition.

CP Nozzle Orientation	Droplet Diameter at Cumulative Volume Fraction (microns)			
	$D_V0.1$	$D_V0.5$	$D_V0.9$	Relative Span
30° (Theoretical) (Bouse 1991)	267	403	609	0.85
90°(Theoretical) (Bouse 1991)	187	273	359	0.63
Measured Droplet Volume				
30° (Left Aircraft Wing)	281	528	862	1.10
30° (Right Aircraft Wing)	233	754	765	0.70
Mean	**257**	**641**	**813.5**	**0.87**
Measured Droplet Volume				
90°(Left Aircraft Wing)	216	416	676	1.10
90°(Right Aircraft Wing)	240	493	734	1.00
Mean	**228**	**454**	**705**	**1.05**

RESULTS AND DISCUSSION

Droplet Size

Verification of the aircraft swath width was made prior to the application with the CP nozzles set at 30° and 90°. Analysis of Kromekote cards demonstrated a spray swath of 12.2 m for the left aircraft wing and 10.9 m for the right wing. With the CP nozzles set at 30° the fine spray droplets moved the full extent of all 48 Kromekote cards (approximately 29 m). An effective swath of 18.3 m was selected for all FSCBG simulations based on calibration of aircraft and equipment.

The theoretical VMD for 30° and 90° is 403 and 273 microns, respectively (Table 2). The measured VMD's were larger at 641 and 454 microns. These VMD's are larger than the desired 200 - 400 microns for an insecticide application. This larger droplet size is due to the presence of Surfix and More in the tank mix. Due to the sensitivity of the area to be treated, an operational application with CP nozzles set at 30° was used. This generated a larger than desired droplet size distribution but minimized potential drift. FSCBG inputs for mass size distribution were adjusted to the measured droplet distribution.

Pesticide Deposition

A comparison of FSCBG aerial simulations and field measurements for the initial ground deposition of permethrin are presented in Table 3. FSCBG simulations over - predicted the initial ground deposition of permethrin by 17% (Block 1) and 10% (Block 3). Simulations under-predicted permethrin ground deposition by 43% (Block 2), 16% (Block 4), and 5% (Block 5). With the exception of Block 2, the predicted depositions are within ± 20% of the measured deposition. This is remarkably good agreement.

The application height of Block 2 (3.04 m) may account for the divergence since the impact of aircraft wake on the spray droplets did not have time to even out. This data together with droplet analysis from Block 2 and 4 show that the droplet distribution for simulations was accurate.

Table 3. Ground deposition of permethrin: measured[1] residue levels vs. predicted[2] residue levels.

Application Site	Stems/hectare	Predicted Deposition (Mean kg ai/ha ± STD[3])	Measured Deposition (Mean kg ai/ha ± STD[3])
BLOCK 1	425	0.0128 ± 0.0033	0.0109 ± 0.0072
BLOCK 2	0	0.0211 ± 0.0093	0.0369 ± 0.0184
BLOCK 3	625	0.0224 ± 0.00114	0.0204 ± 0.0143
BLOCK 4	0	0.0269 ± 0.0086	0.0320 ± 0.0423
BLOCK 5	712	0.0061 ± 0.0062	0.0064 ± 0.0046

[1]Residue levels measured on ground deposition disks.
[2]Residue levels predicted by FSCBG model.
[3]Standard Deviation.

Model Sensitivity

Spray release height is considered a critical input parameter for FSCBG modeling. The sensitivity of this parameter has been evaluated using a forest canopy as a base case (Teske et. al. 1993; Teske and Barry 1993). In the present study, the sensitivity of spray release height versus ground deposition using the input parameters (base case conditions) obtained from the measured field data for new seedling sites (canopy height < 25.0 cm) was evaluated. Simulations using the base case conditions from the permethrin spray (Block 2) resulted in no significant difference ($P>0.05$) in mean deposition at each increment in spray release height between 6.08 m and 21.28 m (Table 4). Significant differences ($P<0.001$) were observed at the lowest application height of 3.04 m and above 24.0 m ($P<0.05$). The standard deviations between spray release heights were significantly different ($P < 0.0001$) when compared to the measured base case release height of 3.04 m (Table 4). Except for ground deposition at 3.04 m, the FSCBG simulated deposition means at each increase in spray release height were not significantly different ($P = 0.78$) than the measured mean at a release height of 22.8 m for permethrin Spray Block 4 (Table 4). Standard deviations from the mean were significantly different ($P = 0.004$) for simulations between the spray release heights of 6.08 and 30.4 m.

FSCBG simulations of stand density (stems/hectare) were completed for the permethrin spray Block 1 (Figure 2). As the number of stems/hectare increased,

ground deposition of the pesticide decreased (Figure 2). No significant differences in mean ground deposition were produced by altering stand density between 243 and 405 st/ha (approximately 40 st/ha increments). Significant differences ($P < 0.05$) were observed for stand densities between 41 and 203 st/ha.

Table 4. Mean predicted ground deposition of total spray solution at altered spray release heights.

Release Height (meters)	Total Ground Deposition of Spray Solution (Mean gm/m^2 ± STD)	
	Permethrin Spray Block 2	Permethrin Spray Block 4
3.04	0.795 ± 0.351	0.656 ± 0.241
6.08	0.410 ± 0.081	0.961 ± 0.182
9.12	0.435 ± 0.077	1.016 ± 0.224
12.16	0.457 ± 0.066	1.069 ± 0.265
15.2	0.476 ± 0.054	1.083 ± 0.282
18.4	0.485 ± 0.102	1.049 ± 0.317
21.28	0.429 ± 0.143	1.020 ± 0.315
24.32	0.311 ± 0.195	1.011 ± 0.335
27.36	0.363 ± 0.195	1.020 ± 0.323
30.4	0.443 ± 0.156	1.030 ± 0.327

Probability of Penetration

Probability of penetration is an FSCBG input parameter that determines the relationship between canopy density and the chances of the pesticide reaching the ground beneath the canopy. Although this may be a critical parameter, it is often difficult to measure or estimate. Canopy density was determined for the permethrin study site with a densitometer. Percent canopy cover was determined with the densitometer and subtracted from 100%, thereby leaving the percentage of openings in the canopy that might allow for pesticide penetration. Based on this procedure, the loblolly pine stands in this study were given the penetration factor of 0.55 (Blocks 1, 3, and 5). This factor did not change between stand densities at the permethrin study site. Simulations of altered probability of penetration resulted in the expected increase in ground deposition with the increase in the probability of penetration (Figure 3).

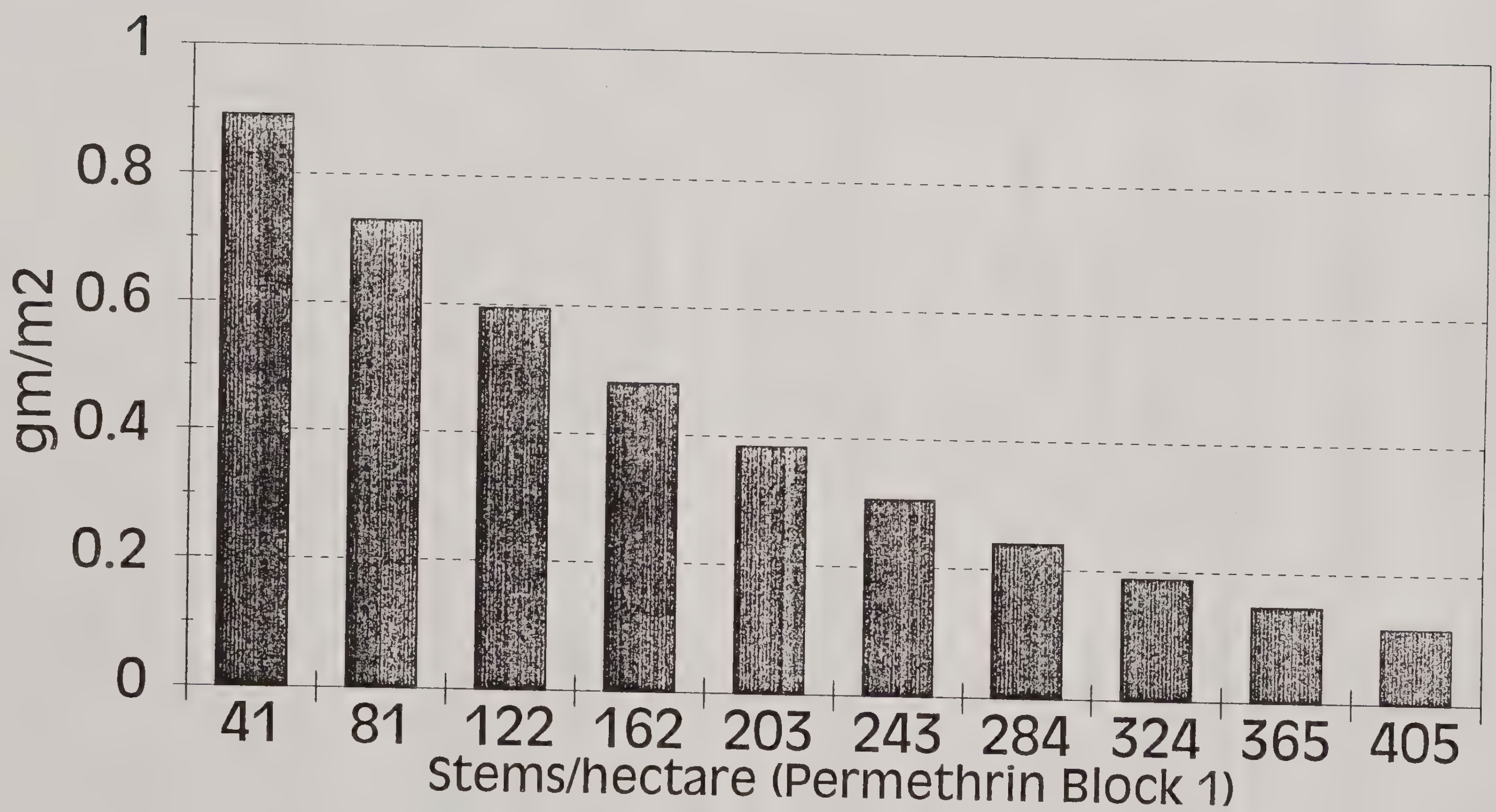


Figure 2. Ground deposition of permethrin as a function of stems per hectare.

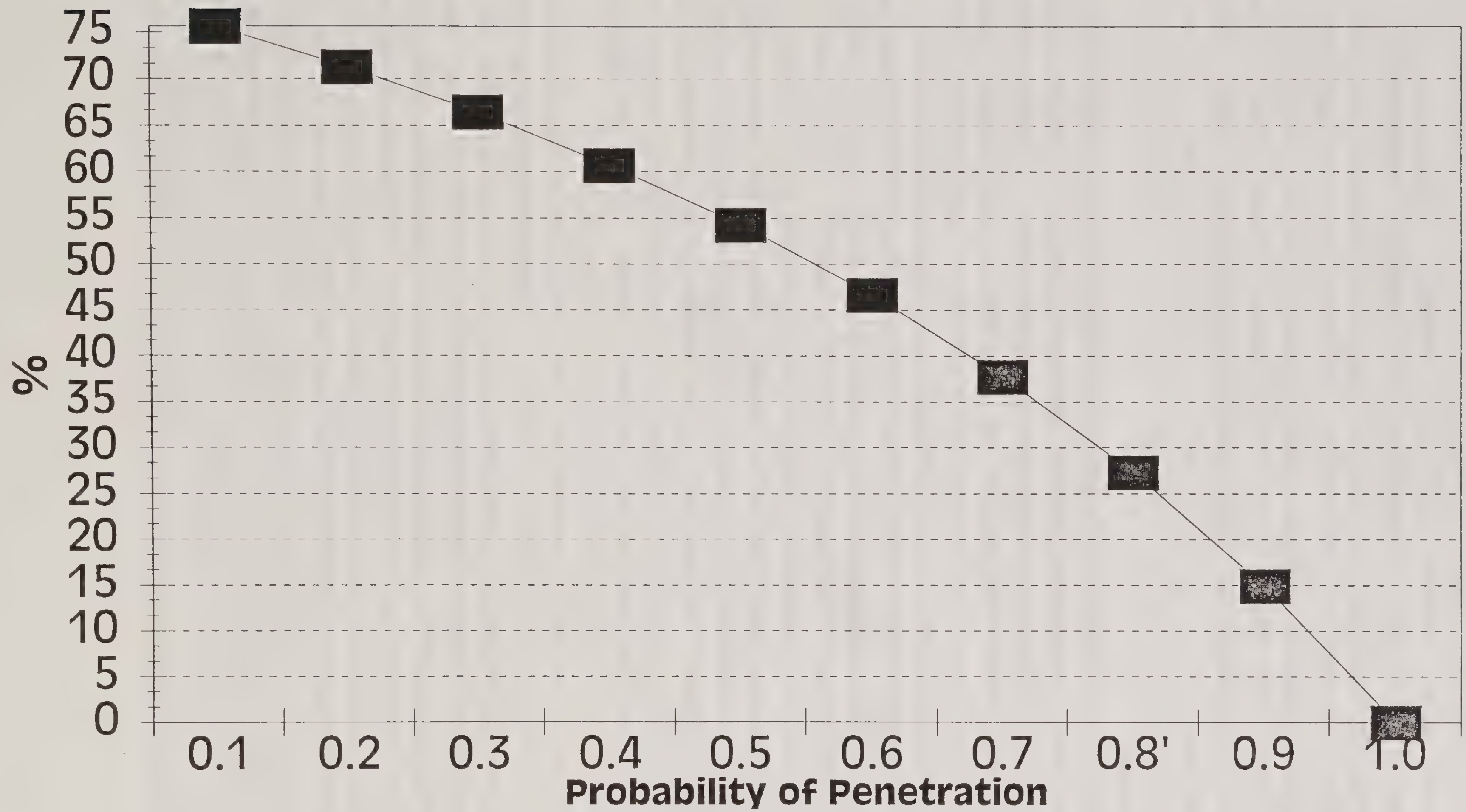


Figure 3. Percent canopy deposition of permethrin as a function of probability of penetration.

Altered probability of penetration between 0.1 and 1.0 for permethrin Block 1 resulted in significant differences ($P<0.01$) in ground deposition.

Probability of penetration is somewhat difficult to measure. The results of this study indicate that ground deposition as compared to the probability of penetration changes slope gradually over the range of 0.1 to 1.0. Therefore, an accurate estimate of this factor is important for accurate predictions. Results of predicted deposition from altered stand densities appear to have a similar effect when stand density is below 243 st/ha. However, methods for precise measurement of stand density and accurate measurements are needed for FSCBG predictions, particularly when stand density is below 243 st/ha.

Forest Management Usage

Uniform coverage in aerial sprays is of particular concern in new seedling sites. Occasionally, individual tree snags on a spray site can make low flight paths impossible and the question of even coverage becomes important. Although this study indicates that altered release height did not dramatically alter total ground deposition, the pattern of distribution did change in the permethrin application (Table 4). The best predicted pattern of distribution for the permethrin sprayed new seedling sites resulted when the spray release height was between 6.08 and 12.16 meters. However, new labeling of this product restricts use above 3.04 meters unless mitigating factors are involved such as snags and applicator safety.

Results of FSCBG aerial simulations approximated on-site measurements. FSCBG accepts input for meteorologic conditions for inside and outside the canopy. Wind speed, wind direction and temperature inside the canopy can vary greatly from measurements obtained outside the canopy. The height from which these measurements are obtained can also alter the accuracy. Although difficult, monitoring wind speed, wind direction and temperature at the spray release height provides a more accurate measurement for FSCBG predicted deposition and drift.

FSCBG can be useful in preparing, conducting and analyzing aerial pesticide applications. For operational sprays, FSCBG is useful in determining spray release height for better coverage and it is useful in predicting drift. Continued testing of the model indicates that accuracy of simulated spray deposition is a function of how input parameters (weather conditions, release height, aircraft, stand density, etc.) react in combination rather than as single units. The parameters altered for sensitivity analysis in this study did not result in great variation (within a specific range) in mean ground deposition. However, the deposition pattern and amount of drift changed as spray release height was altered. The FSCBG user learns that successful modeling of a spray application depends on accuracy of field measurements and data collection. Monitoring data from operational sprays familiarizes the new FSCBG user with input parameter selections and guides data collection. This particular study demonstrates the importance of accurate field measurements for enhancing FSCBG predictive capabilities.

CONCLUSIONS

Uniform coverage in aerial pesticide applications is of particular concern. The following conclusions can be derived from the results of this study:

1. FSCBG closely predicted the measured deposition of permethrin.

2. The CP Nozzle should be operated at a 90° angle to obtain the appropriate droplet size range when used for the aerial spray of insecticides. The 30° angle produces droplet sizes in a range too large for an effective insecticide spray.

3. The CP Nozzle should be operated at a 90° angle to obtain the appropriate droplet density. The recommended droplet density for an effective insecticide spray is 20 drops/cm^2. In this study, droplet density fell below the minimum requirement (15.9 drops/cm^2) due to the 30° nozzle orientation during the aerial spray.

4. Release height is a critical factor in determining a successful spray application. Flying too low can adversely affect application uniformity and increase the possibility of streaking. Releasing spray from excessively high altitudes increases evaporation, wind effects, and drift. The results of this study indicate that a release height of 6.08 - 12.16 m, when meteorological conditions are similar to those found during the permethrin spray, generates a more even pattern of pesticide distribution when spraying new seedling sites (bare ground). However, release height may need to be altered depending on the pesticide used and the weather conditions prevalent at the time of aerial application. FSCBG is a useful tool in determining this critical parameter.

ACKNOWLEDGEMENTS

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Marilyn A. Buford, Editor
Forestry Sciences Laboratory, USDA Forest Service
P.O. Box 12254, Research Triangle Park, N.C. 27709
Telephone: (919) 549-4061 FAX: (919) 549-4047

April 21, 1994

Dr. Parshall B. Bush
Cooperative Extension Service
College of Agriculture
The University of Georgia
Athens, GA 30602

Dear Dr. Bush:

I have received your revised p. 12 of "Use of FSCBG to predict pesticide deposition on a Piedmont pine seed orchard" (SJAF 1196). I believe your revision satisfies the reviewers' concerns and I am pleased to accept this manuscript for publication in the Southern Journal of Applied Forestry.

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USE OF FSCBG TO PREDICT PESTICIDE DEPOSITION ON A PIEDMONT PINE SEED ORCHARD

Parshall B. Bush, Sandra S. Chapman, Yvette C. Berisford, USDA Cooperative Extension Service, Agricultural Services Laboratory, The University of Georgia, Athens, GA 30602; and **John W. Taylor,** USDA Forest Service, R8, 1720 Peachtree Road NW, Atlanta, GA 30367

ABSTRACT. This study demonstrates the usefulness of the FSCBG aerial simulation model as a forest management tool. In general, the model closely predicted the measured deposition of bifenthrin in a pine seed orchard. An exception was the August application during which wind gusts caused the pesticide to drift further from the application area than predicted by the model. FSCBG tended to under-predict drift and evaporative losses based on the input parameters of this study. Simulations of other registered pine seed orchard pesticides demonstrated no potential environmental risk to representative aquatic organisms in surrounding ponds or waterways based on the test conditions presented.

Corresponding author: Parshall B. Bush, Agricultural Services Laboratory, 110 Riverbend Rd., Athens, GA 30602

Phone (706) 542-9023

Pine forest management in the southern United States relies heavily on the use of genetically improved seedlings to achieve high productivity. Productivity is threatened if seed and cone insects are left uncontrolled (Ebel et al. 1980). Insects can cause annual seed production losses exceeding 90 percent (Barry et al. 1984, Fatzinger et al. 1980). Therefore, heavy and frequent insecticide applications are often required to prevent seed losses. The increased frequency of aerial applications of pesticides for insect control in seed orchards establishes the need for predicting pesticide ground deposition and drift, particularly when drift or hydrological off-site movement poses a threat to sensitive organisms in nearby aquatic habitats. The Agricultural Dispersal model, AGDISP (Bilanin et al. 1989), and the USDA Forest Service Cramer-Barry-Grim aerial spray model, FSCBG (Teske et al. 1993), have predicted realistic pesticide deposition for a desert application (Boyle et al. 1975) and a Douglas-fir seed orchard in Oregon (Teske et al. 1991). FSCBG was used in the present study to estimate initial pesticide loading and drift in a pine seed orchard. The objectives of this study were to, (1) determine how well the FSCBG model predicts pesticide deposition by comparison with actual field data; (2) determine the usefulness of the simulation model for management practices; and (3) determine the potential impact of initial pesticide loading and drift on nearby aquatic organisms.

METHODS AND MATERIALS

Study Site

The study site was the Mead Coated Board Seed Orchard located in the Georgia Piedmont, approximately 80 km south of Athens, GA, near the town of Eatonton, GA (Putnam County). It is planted in loblolly pines (Pinus taeda L.) which are spaced 7 m x 7 m apart (approximately 100 stems/ha). The groundcover is complete and dominated by coastal bermuda grass (Cynodon dactylon [L.] Pers.). The orchard terrain is rolling with a maximum relief of 20 m on 6-10% slopes. Soils are loam and clay textured Typic Hapludults of the Davidson series. Average annual precipitation is 1400 mm. For a more complete orchard description, see Bush et al., 1986.

The treated area (Figure 1) was approximately 8.09 ha. An open area of bermuda grass covered 2.83 ha of the treated area and the remaining 5.26 ha consisted of loblolly pine for cone production. A bare soil site (28 m x 28 m) was established in the open grass area on the north end of the spray block.

Application and Initial Ground Deposition of Bifenthrin

Bifenthrin (Capture® 2EC) was aerially applied by a bi-winged Grumman Ag Cat 164B to a 8.09 ha block on June 21, August 9, and September 6, 1991 at a rate of 0.197 kg AI/ha (Figure 1 and Table 1). The spray boom contained 35 D10-46 hollow cone nozzles (Spraying Systems Co., Wheaton, IL.) which were spaced 17.5 cm apart. The first nozzle was approximately 1.85 m from the end of the wing and the distance between the first nozzle and the aircraft body was 1.3 m. Keyacid® Rhodamine WT liquid dye

(Keystone Aniline Corporation) (0.2 - 0.4% of total volume) was added to the aerial spray mixture for the first two applications to aid in spray droplet characterization. The dye was increased to 0.4% for the second application to intensify visibility. The dye was intercepted on Kromekote cards which were placed adjacent to ground deposition disks. Prior to the bifenthrin applications (19 June and 9 August, 1991), approximately 70 Kromekote cards were labeled and placed on the ground (every 0.9 m) across a designated airstrip for spray characterization. The aircraft flew approximately 6.08 m above the cards at 42.5 m/s and released the spray solution of Rhodamine WT dye and water (June tank mix = 188.5 L of water + 0.48 L of dye: August tank mix = 188.2 L of water + 0.757 L of dye).

The initial ground deposition of bifenthrin was calculated from residues intercepted on 9 cm diameter glass fiber disks (Fisher) placed on the ground in the bare soil site, beneath the loblolly pine canopy in the forested site, along the perimeter of each pond, on platforms in each pond, along the stream, and on all wells. Sixty-four disks were placed in the forested site and sixty-four disks were placed in the bare soil site for each application. One disk and one droplet characterization card were placed at every 4 m intersection (where the horizontal and vertical lines intersected) of a grid system set out in the forested site. A total of 64 disks and their accompanying cards were placed in eight rows, each row having 8 disks.

Ground deposition disks and accompanying spray droplet characterization cards were placed in pairs around the perimeter of the 28 m x 28 m bare soil site (Figure 1). The

perimeter was selected because soil samples were collected from within the 28 m x 28 m bare soil site for another study and any disks placed in this area would intercept the pesticide, thereby influencing the amount of bifenthrin available for leaching into the soil.

Sample Handling

Each disk was placed in a numbered petri dish, and then each dish was closed, wrapped with aluminum foil and placed in a designated field location on the day prior to pesticide application. On the morning of the application, the petri dishes were opened to expose the glass fiber disks. Petri dishes were re-covered within 30 minutes after pesticide application to prevent contamination and placed on ice for transport to the laboratory.

Extraction and Quantitation

Each glass fiber disk was transferred to a 15 ml glass culture tube and 10 ml of trimethyl pentane was added. The sample was shaken for 5-10 seconds and allowed to settle. Samples were sonicated in an ultrasonic bath for 15 minutes and aliquots were withdrawn for GC analysis. Quantitation of bifenthrin was conducted using a Tracor Model 222 gas chromatograph equipped with a Ni^{63} electron capture detector and a 2 M x 4 mm I.D. glass column packed with 3% OV-1 on Chromosorb WHP. The detector, inlet, and column temperatures were 350°C, 260°C, and 240°C, respectively. The carrier and purge gases were 5% methane/95% argon, with a flow rate of 45 ml/min. and 10 ml/min., respectively. Residue levels were determined by comparison of peak heights in sample chromatograms to those of analytical standards obtained from FMC

Corporation. A reagent blank and spike sample were included in each set of analyses. The detection limit was set at 0.00145 mg/m^2.

Analysis of Kromekote Cards

The spray droplets deposited on Kromekote cards from the aircraft calibration and the bifenthrin applications were analyzed by an image analyzer (Sanderson 1991) and/or the Automatic Spot Counting and Sizing Program (ASCAS version 4.0) on a personal computer (Teske 1992). When the image analyzer was not sensitive enough to read deposits on a card, the ASCAS program was used for analysis. A spread factor of 2.20 was used in computations for relating droplet diameter to stain diameter. Results were used for determining an effective swath width and comparing measured field droplets with the theoretical droplet size category used in FSCBG simulations.

Input Parameters for FSCBG Simulations

The current FSCBG Version 4.0 was installed and operated on an IBM 386 compatible computer equipped with a math coprocessor. Initial simulations were conducted using parameters presented in Table 1.

Canopy height used for simulations averaged 15 m. Stand density was approximately 100 stems/ha. A penetration probability of 0.38 was used based on Teske et al. (1991). A vegetative element size of 3 cm was assumed.

Aircraft and equipment characteristics required for model input were obtained from the pilot and FSCBG default values for the Schweizer Ag Cat Super 164 Biplane. The spray boom contained 35 D10-46 hollow cone nozzles and FSCBG is limited to 20

nozzles in a simulation, therefore 17 nozzles were used in simulations (one nozzle centered under the aircraft and 8 symmetrically placed under each wing). The aircraft made 12 passes (flight lines) over the site, depositing the application solution at a rate of 93.5 L/ha with a swath width of 18.3 m. The spray volatile fraction of the carrier was 0.991 (calculated as the ratio of water to total solution). Drop size distributions were obtained from the FSCBG drop size library (Skyler and Barry 1991). The minimum drop diameter was 5.0 microns. Aircraft speed and spray release height were specified by the applicator. Meteorological characteristics (wind speed, wind direction, ambient temperature and relative humidity at 1 m height) were recorded by a weather station at the orchard. Wind speed during the August application ranged from 1.3 m/s to gusts of 3.58 m/s. A wind speed of 3.58 m/s was used for August simulations to account for the gusts. The radiation index parameter was estimated as follows: dark to 8:00 am =+1.0, 8:00 am to 10:00 am= +2.0, 10:00 am to noon = +3.0. The radiation index was reduced by 1 for the June application to account for dense ground fog.

Additional FSCBG simulations for determining the potential impact of pesticide deposition on aquatic organisms were based on spray parameters and weather conditions from 9 August, 1991 spray data (Table 1). The FSCBG input parameters for the August spray date were selected to present the greatest chance for drift and contamination of nearby aquatic habitats.

RESULTS AND DISCUSSION

Analysis of Kromekote cards for the June application calibration demonstrated a spray swath of 11.0 m for the left aircraft wing and 12.8 m for the right wing with a slight hole to the right of the center of the aircraft (probably due to prop wash). Fine spray droplets moved the full extent of the Kromekote cards and beyond for the right wing. Card analysis of the August calibration spray indicated a spray swath of 12.8 m for both the left wing and the right wing, again with a slight hole to the right of the center of the aircraft. Fines for the August calibration moved the full extent of all 70 cards (approximately 64 m). An effective swath of 18.3 m was selected for all FSCBG simulations. The volume median diameter (VMD) determined by image analyzer and ASCAS analysis for the three calibration passes (396, 379, and 405 microns at a release height of 3.0 m) was similar to the VMD (441 microns) used in the FSCBG simulations. The droplet size category selected for FSCBG simulations was from a theoretical range based on wind effects and spray nozzle characteristics for the particular nozzles used in the actual spray (Skyler and Barry 1991). The measured VMD of the droplets from the bifenthrin applications were 380, 353, 348, and 334 microns at a release height of 18.5 m. The decreased measured VMD for the bifenthrin sprays is probably due to evaporative losses during application.

Results of the FSCBG simulations for ground deposition of bifenthrin are presented in Figure 1 and Table 2. The model under-predicted bifenthrin concentrations on the bare soil site for the June application by 23.5% and over-predicted the

concentrations by 67% and 32% for the August and September applications, respectively. The mean amount of bifenthrin deposited on the bare soil site ranged from 48-67% of the applied level among the three spray dates. The model over-predicted measured residue levels in the forested site for the June (+56%) and August (+136%) applications and under-predicted the September application deposition (-13%). The measured mean bifenthrin deposition in the forested site was 26-58% of the applied level.

The model predictions compared favorably with measured deposition data for a first approximation with limited parameter modifications. Although the model tended to over-predict ground deposition, measured values may be low because the bare soil site is adjacent to the loblolly pine stand. Model simulations of ground deposition at the bare soil site excluded the effects of surrounding vegetation.

The FSCBG model tended to under-predict drift and evaporative losses. The probability of canopy penetration using an interception ratio of 0.38 (Teske et al. 1991) was predicted to range from 46.4% to 54.7% and the measured value ranged from 24.5 to 45.8%. Penetration probability is considered a critical model parameter (Teske et al. 1991, Teske and Barry 1993). Ground deposition in a forested site decreases as the probability of penetration decreases. The use of a lower penetration value would decrease the predicted values. An additional contributing factor to the discrepancy in model predictions versus measured values is the position of the weather station. Weather data was collected at 1 m above the ground and spray release height was 18.5 m.

Possibly, wind speed was higher at the spray release height. This is especially true for the August application when winds gusted to 3.6 m/s. This could also account for the over-estimation (+136%) of deposit in the forested site for the August application.

To evaluate potential risk to aquatic environments, the predicted pesticide deposition was compared with one-tenth the LC_{50} concentration for bluegill sunfish (Lepomis macrochirus) and daphnia (Daphnia spp.). The use of this measurement was based on the assumption that concentrations of less than one-tenth the LC_{50} pose no acute risk to aquatic organisms (U.S. Environmental Protection Agency 1986). Bluegill and daphnia were selected to represent aquatic vertebrate and invertebrate species, respectively. Figure 2 represents the predicted spray concentration outer boundaries for areas which would receive: A) one-tenth the LC_{50} dose for bluegill sunfish (assuming an average depth of 0.304 m of water), B) one-tenth the LC_{50} concentration for daphnia (assuming an average depth of 0.304 m of water), and C) an analytically detectable concentration of bifenthrin on the glass fiber disks. The average depth of 0.304 m of water was used to facilitate conversion of model generated mg/m^2 to water concentrations of mg/kg. This also reflects expected concentrations in shallow, near shore zones where highly susceptible small fish will be present.

The June and September, 1991 applications were conducted under ideal wind conditions and showed little drift or detectable deposition (detection limit = 0.00145 mg/m^2) on or in the adjacent water impoundments (Table 3, Figure 2). One or more Rhodamine WT dye droplets were found on two of the 11 cards at the control pond, but

no bifenthrin residues were detected. Cards and deposition disks placed at the dam and the upper end of the treatment pond contained no visible (Rhodamine WT dye) or detectable bifenthrin residues. The FSCBG model treated the area to the northeast of the spray block as an bare soil area and may have overestimated the extent of spray drift, or measurement of field drift may not have been sensitive to small deposit levels.

During the last part of the August application, winds gusted to approximately 3.58 m/s (measured 1.22 m above ground) and drift of the pink application solution "approached" the control pond, treatment pond, and stream areas. From the observers' vantage point, it was not possible to determine if the application solution actually reached the ponds or stream or only "approached" them. However, bifenthrin residues and/or the pink Rhodamine WT dye which colored the application solution were detected at most monitoring points around or on each pond and along the stream (Table 3).

Weather conditions were ideal during the September application and no spray drift was predicted or measured at the flume (approximately 152 m from application site), upper end (approximately 240 m from application site) or at the dam (approximately 399 m from application site) of the treatment pond (Table 3, Figure 2). One sample from the control pond site contained 9.1 ug of bifenthrin and may represent contamination of the disk or a single large drop from the aircraft.

After FSCBG model simulations of bifenthrin deposition and drift were compared with measured results from the on-site application data, simulations of other pesticides used on seed orchards were conducted to determine the potential impact of pesticide

deposition on bluegill sunfish and daphnia (Figure 3). Spray parameters and weather conditions from the 9 August, 1991 application were selected for FSCBG model simulation inputs (Table 1). A value of one-tenth the LC_{50} of acephate (Orthene®), esfenvalerate (Asana® XL), permethrin (Pounce®), azinphosmethyl (Guthion®), and malathion (Malathion® 57EC) was selected as the lowest concentration which would adversely affect either species (Table 4, U.S. Environmental Protection Agency 1986). With the exception of acephate, model simulations predicted the deposition of at least one-tenth the LC_{50} concentrations of each pesticide within the treated area and approximately 50 to 100 meters down wind of the treated area. The azinphosmethyl deposition contour based on one-tenth the LC_{50} for bluegill sunfish is presented in Figure 3. Although azinphosmethyl had a slightly greater impact, the contour represents the deposition pattern for all pesticides evaluated in this study. The azinphosmethyl deposition contour for daphnia is representative of all the selected pesticides (Figure 3). Based on the spray parameters (1 pass at the labeled rate) and weather conditions used in simulations, the model predicts that drift from the application of these pesticides will not result in one-tenth the LC_{50} concentration in adjacent waterways or ponds.

A limiting factor in hydrologic modeling of pesticide runoff and migration to groundwater is the estimation of initial pesticide loading and distribution within the canopy. Foliar residues are generally more susceptible to volatilization, photolysis, and

foliar absorption than litter bound residues (Dowd et al. 1993). Surface residues (0- 0.5 cm soil depth) have the greatest potential for offsite movement in surface runoff and migration to groundwater. The interaction of application method, pesticide and vegetation density affect pesticide loading and distribution. FSCBG simulation of bifenthrin application predicts 10.0, 12.3 and 21.8 % evaporative losses, 46.4, 54.7 and 48% foliar interception and 43.5, 31.8 and 30.2% ground deposition for the June, August and September applications, respectively. Therefore, 30-43% of the applied pesticide is highly susceptible to surface runoff.

Results of FSCBG modeling outputs approximated on-site measurements. Although the model is limited in its ability to predict the effects of various off-site vegetation, it does estimate the extent of potential drift. Assessing the potential for contamination to adjacent aquatic environments is a difficult task for seed orchard managers. This type of model can be a useful tool to determine factors that influence the off-site movement of pesticides in a spray monitoring program.

ACKNOWLEDGMENTS

The authors wish to thank John W. Barry, Milton E. Teske and Patricia J. Skyler for their advice and assistance concerning the use of the FSCBG aerial spray model. Larry R. Barber, USDA-Forest Service Forest Health R8, supplied the analysis and interpretation of card data. We also thank Bill Arnold, Manager of the Mead Coated

Board Seed Orchard for his technical support. This study was supported by the USDA Forest Service, Forest Pest Management, Technology Development Project funds.

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TABLE 1. Summary of bifenthrin (Capture® 2EC) application data for FSCBG simulations.

	Application Date		
	June 21, 1991	August 9, 1991	September 6, 1991
Aircraft Speed	42.47 m/s	42.47 m/s	42.47 m/s
Aircraft Weight	2421 kg	2421 kg	2421 kg
Aircraft Wingspan	12.93 m	12.93 m	12.93 m
Propeller Radius	1.342 m	1.342 m	1.342 m
Blade RPM	2300	2300	2300
Flight Bearing	-----------------220° and 040° west south west----------------		
Spray Release Height	18.5 m	18.5 m	18.5 m
Swath Width	18.3 m	18.3 m	18.3 m
Swath Length	423 m	423 m	423m
Bifenthrin Conc. in Spray Solution	2110 ppm	2100 ppm	2115 ppm
Rate (kg AI/ha)	0.197	0.197	0.197
Volatility	0.991	0.991	0.991
Hectares Treated	8.09	8.09	8.09
Canopy Height	15.0 m	15.0 m	15.0 m
Stand Density	100 st/ha	100 st/ha	100 st/ha
Probability of Penetration	.38	.38	.38
Element Size	3.0 cm	3.0 cm	3.0 cm
Temperature	31.1°C	32°C	32°C
Relative Humidity	68%	65%	85%
Wind Speed	1.34 m/s	3.58 m/s	0.45 m/s
Wind Direction	240°	265°	240°
Time of Application	11:00 am	9:00 am	8:00 am

TABLE 2. Mean ground deposition of bifenthrin: measured[1] residue levels vs. predicted[2] residue levels.

Application Date		Bare Soil Site (Mean kg a.i./ha ± STD[3])	Forested Site (Mean kg a.i./ha ± STD[3])
6/21/91	Measured	0.132 ± 0.043	0.050 ± 0.032
	Predicted	0.101 ± 0.045	0.078 ± 0.048
8/9/91	Measured	0.094 ± 0.099	0.025 ± 0.017
	Predicted	0.157 ± 0.019	0.059 ± 0.018
9/6/91	Measured	0.106 ± 0.045	0.062 ± 0.050
	Predicted	0.140 ± 0.041	0.054 ± 0.050

[1]Residue levels measured on ground deposition disks.
[2]Residue levels predicted by FSCBG model.
[3]Standard Deviation.

TABLE 3. Comparison of the mean measured deposition levels (from ground cards) with mean FSCBG predicted concentrations.

		Application (mg/m^2)								
		JUNE			AUGUST			SEPTEMBER		
Study Sites	N[1]	D	M	P	D	M	P	D	M	P
Control Pond	11	2+	<0.015	<0.001	7+	<0.015	<0.001	NA	<0.015-1.433*	<0.001
Dam	6	0+	<0.015	<0.001	6+	<0.015-0.033	<0.001	NA	<0.015	<0.001
Upper End of Pond	4	0+	<0.015	<0.001	3+	0.020-0.039	<0.001	NA	<0.015	<0.001
Flume	2	0+	<0.015	<0.001	1+	0.044	0.003	NA	<0.015	<0.001
Well#3	2	2+	<0.015-0.040	0.006	2+	1.077-1.294	0.773	NA	0.033-0.039	<0.001

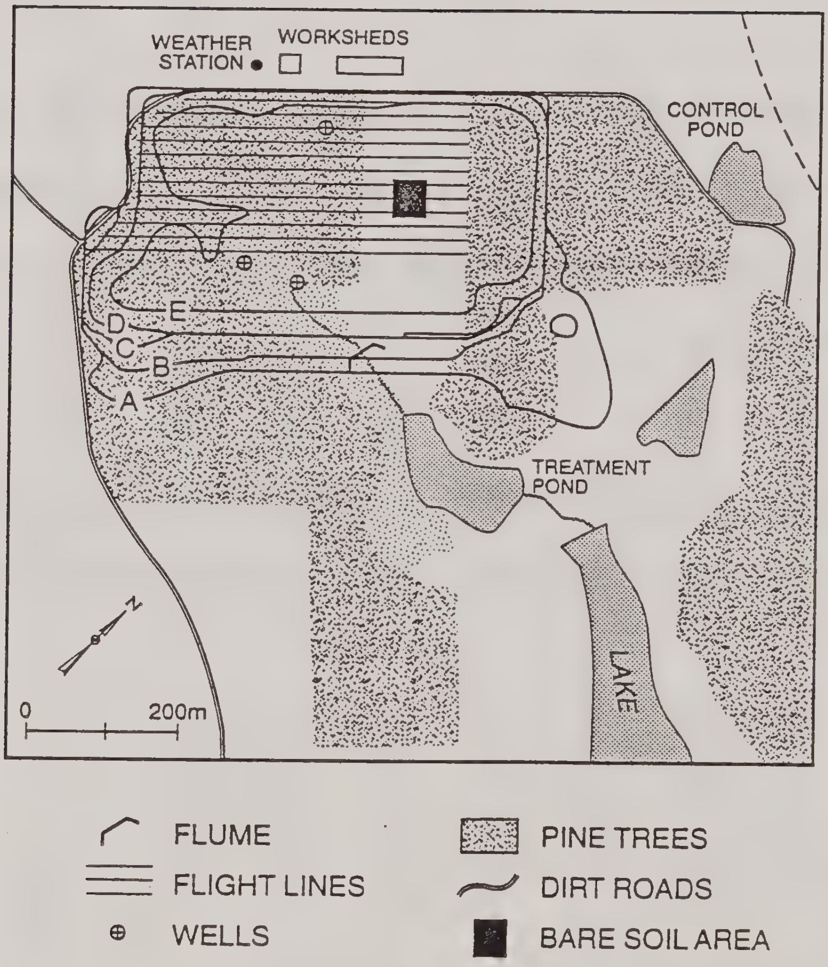
[1]N= number of spray discs per study site; D= number of discs containing visible dye; M= measured bifenthrin concentration in mg/m^2; P= FSCBG predicted concentrations; NA= dye not added to September application.
*One sample was found to contain 9.1 ug/disc probably representing contamination of the disc or a single large drop from the aircraft.

TABLE 4. Pesticide deposition (mg/m^2) required to produce one-tenth the LC_{50} concentration of bluegills and daphnids in 0.304 m of water[1].

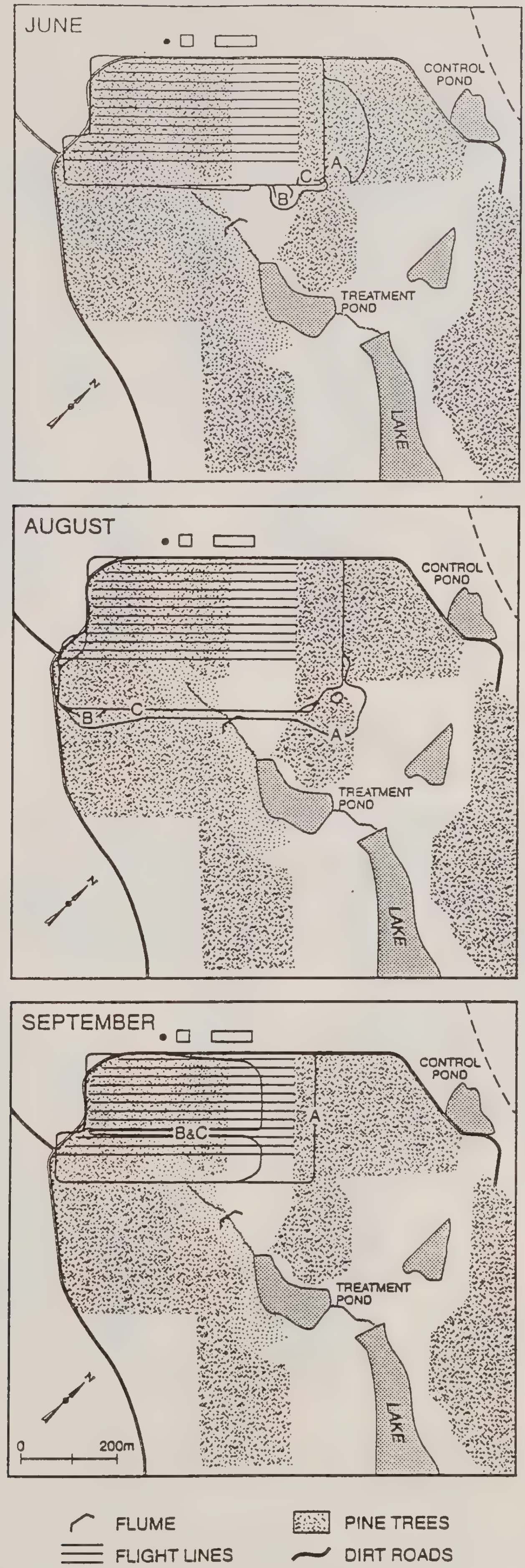
Pesticide	Bluegill LC_{50}	mg/m^2	Daphnia LC_{50}	mg/m^2
Esfenvalerate	0.42-1.65 ppb	0.0127-0.0502	2.1 ppb	0.0633
Permethrin	4.5-14.0 ppb	0.137-4.256	1.26 ppb	0.0383
Azinphosmethyl	8.0-52.0 ppb	0.243-1.58	0.15-21.0 ppb	0.004-0.638
Bifenthrin	0.15-0.35 ppb	0.0045-0.0106	0.07-1.6 ppb	0.002-0.048
Malathion	44.0-274.0 ppb	1.33-8.33	1.0-1.8 ppb	0.046
Acephate	750->1000 ppm	1,520-34,400	>50.0 ppm	1,520

[1] Mayer, F.L., Jr. and M.R. Ellersieck. 1986. Manual of acute toxicity: interpretation and data base for 410 chemicals and 66 species of freshwater animals. U.S. Fish and Wildlife Service Resource Publication 160. 33 p.

LIST OF FIGURES



A= $0.10E^{-03}$ gm/m^2
B= $0.10E^{-02}$ gm/m^2
C= $0.10E^{-01}$ gm/m^2
D= 0.10 gm/m^2
E= 1.00 gm/m^2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SEPTEMBER
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PINE TREES
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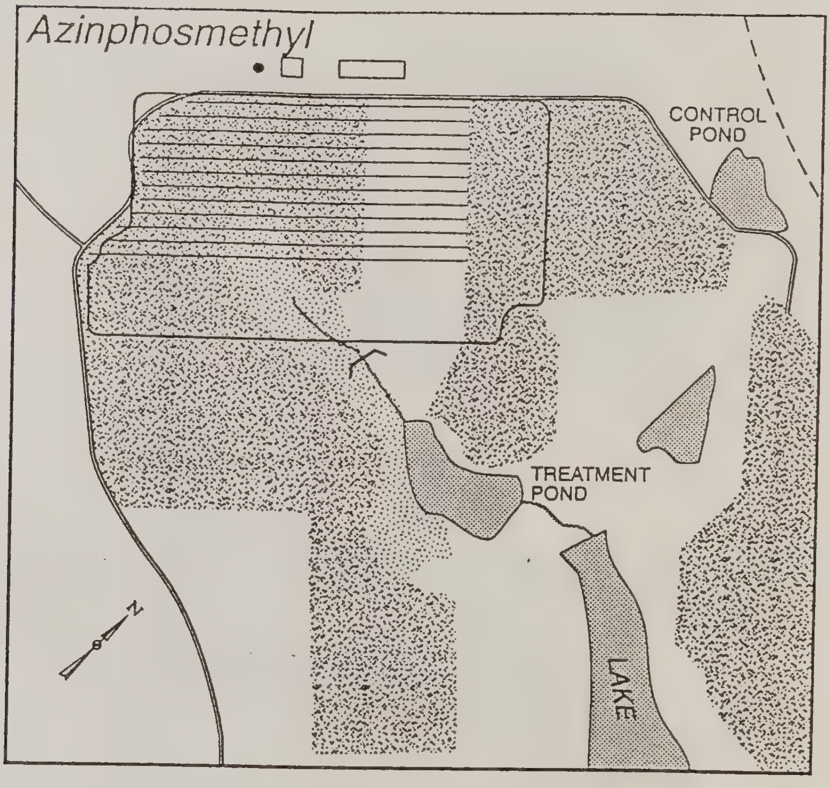
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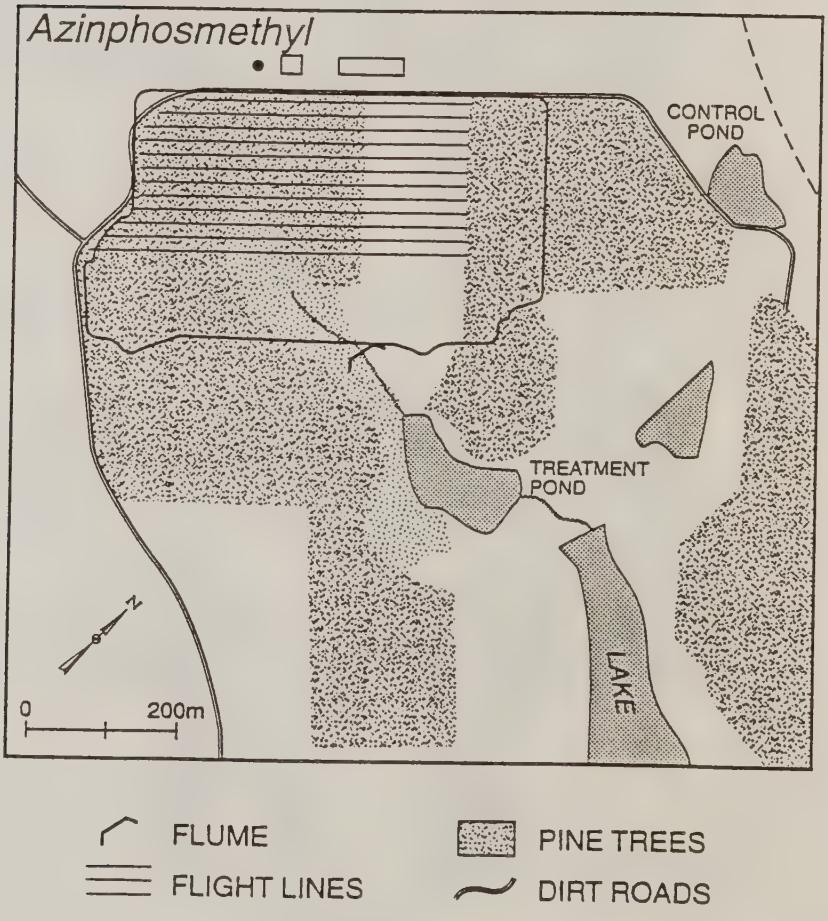
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FLUME
FLIGHT LINES
PINE TREES
DIRT ROADS

Milt Teske
Continuum Dynamics, Inc.

USDA Forest Service
Aerial Spray Models
AGDISP and FSCBG

1994 Model Status Report

Milton E. Teske
Continuum Dynamics, Inc.

National Spray Model
and Application Technology
Steering Committee

Kansas City, Missouri
22 June 1994

Summary

Status of the Models

Technology Transfer

Publications and Reports

Anticipated Modeling Features

Unsolved Problems

Other Topics

Status of the Models

FSCBG

4.3 released in March 1994

New Features:

Menu Detail Level
Help
Near-Wake Handoff

AGDISP

6.0 Maturity -- further development will occur as the spray drift model for SDTF

User Group Count: 42 AGDISP and 89 FSCBG

Menu Detail Level

1. FSCBG "lite"

2. Standard

3. Advanced

Looking into further simple modeling techniques to extract some of the "quick and dirty" answers that have been urged at this meeting over the last several years.

On-Line Help

```
Menu>
? help  <esc> go back  <return> select current
```

Characteristics:

- Context sensitive
- Fully indexed
- Layered
- Optimized search engine

Combines the User Manual, One-on-One Manual, and Training Session material, with all new program features added.

You may never have to read the documentation again!

Near-Wake Enhancements

We have finished a detailed examination of FSCBG predictions in significant downwind drift situations. Our findings suggest:

1. The development of a clear definition of the near-wake of an aircraft, and the hand-off of model calculations from the near-wake model (solving Lagrangian equations for the spray trajectories) to the far-wake model (solving Gaussian equations for the dispersion).

2. The development of a clear relationship between downwind dispersion and aircraft release height, and the consequences evident in deposition at large distances downwind.

3. The realization that drop size distributions must be resolved with categories far greater than previously anticipated.

4. The demand, as always, for accurate meteorological, aircraft, and deposition field measurements before attempting serious model comparisons.

Near-Wake Handoff

Three solution paths in FSCBG 4.3:

1. The way it was ("Vortex Decay"): where the transfer from Lagrangian to Gaussian occurs when the vortex strength no longer influences the spray material

2. Lagrangian to the top of the canopy or the ground: now includes the FSCBG canopy model in the near-wake AGDISP model

3. Lagrangian to within four standard deviations of the top of the canopy or the ground: transition to full Gaussian solution -- no near-wake plot capability

Drop Size Manipulation

1. As is

2. Interpolation -- volume interpolation between existing drop sizes

3. Extrapolation -- root-normal to small drops, and a criterion on number of desired drop sizes (100 maximum)

Atomization

We are publishing our non-Newtonian technique for collapsing drop size distributions, but this technique requires data base entries (not presently available) to develop the curve-fit parameters. Once in place, we should be able to extrapolate to drop size distribution types not wind-tunnel tested. But much data is needed to extend these results.

Evaporation

We are about to release a report on nonwater evaporation studies performed over the last ten years by the USDA Forest Service, including the study of three materials at SRI. The results will demonstrate:

1. The use of the classic D^2 law

$$D_o^2 - D^2 = \lambda t$$

   works very well when the data is properly normalized. Nonwater material (such as Bt) appears to evaporate as water until its nonvolatile fraction is reached.

2. Nonvolatile fractions are a possible experimental problem. Studies at UConn, Wooster and RPC (SDTF) on the same materials give very different results for nonvolatile fraction.

FSCBG User Group

89 members

Newsletter #5

Breakdown by country:

Australia	4
Canada	7
Chile	1
England	1
New Zealand	16
USA	60
USDA FS	19 (21%)

Technology Transfer

New Zealand Training Session: 31 Jan to 2 Feb

New Zealand Refresher Session: 3 Feb

Workshop: "Spray Drift Management - Can Computer Models Help?"

- > Milt
- > Harold
- > J. Picot (PKBW)

Canada:

1993 Advanced Forest Herbicides Course: 1 Oct 1993
Next One: 25 Sept 1994

Marana

Publications

M. E. Teske, A. J. Bilanin and J. W. Barry. 1993. Decay of aircraft vortices near the ground. *AIAA Journal* 31:1531-1533.

M. E. Teske, A. Z. MacNichol and J. W. Barry. 1994. USDA Forest Service spread factor technology database. Pesticide Formulations and Application Systems: 14th Volume. ASTM STP 1234. F. R. Hall, P. D. Berger and H. M. Collins, eds. American Society for Testing and Materials: Philadelphia, PA.

M. E. Teske and A. J. Bilanin. 1994. Drop size scaling analysis of non-Newtonian fluids. *Atomization and Sprays* (to appear).

M. E. Teske, J. W. Barry and H. W. Thistle, Jr. 1994. Environmental fate and accountancy. American Chemical Society (to appear).

M. E. Teske, J. W. Barry and H. W. Thistle, Jr. 1994. Aerial spray drift modeling. Environmental Modeling Volume II: Computer Methods and Software for Simulating Environmental Pollution and its Adverse Effects. P. Zannetti, ed. Computational Mechanics Publications: Southhampton, England. pp. 11-42.

Reports

Model Comparisons:

C-130	FPM 93-10
1988 Davis characterization	FPM 93-12
1991 Davis virus	FPM 94-2
Rennic Creek	

Statistics:

C-47	FPM 94-11

Others:

Nonwater

Anticipated FSCBG Features

Anticipated release of FSCBG 4.4 at the end of 1994, to all active users. Its new features will include:

Nonparallel, nonracetrack flight lines
Discrete canopy option
Dry materials

FSCBG Demo Program

1993 Identified Needs

1. Drift tests of orchard airblast sprayers, and implement validated model into FSCBG

2. Link GPS on-board aircraft to FSCBG real-time simulation

3. Expert system: GypsES implementation

4. Evaluate tree or shelter belt potential for reducing drift, and implement model into FSCBG

5. "Hint Book" guidelines for sampling, meteorology instrumentation, data collection, quality control testing, useability of FSCBG

6. Complex terrain: VALDRIFT

7. Pursue model development, enhancement, and technology transfer of FSCBG

Unsolved Problems

Some of the unsolved FSCBG problems are:

Along-wind flight lines

Flight line edge effects (turning the flight lines on and off)

Canopy top deposition and turbulence

Card lines vs flight lines at an angle

Continued utility of Gaussian plume model

Other Topics

Downwash field study on fire-fighting helicopters

User Group Support -- Training Session?

Spray Drift Task Force

U. S. Air Force Fuel Jettisoning contract:

Evaporation of JP-4 and JP-8 fuels (multicomponent)
Drop size distribution at 200 mph

Jim Hadfield
R-6

MESSAGE SCAN FOR JACK BARRY

To   J.BARRY:R05H

From: James S. Hadfield:R6/PNW   Host: R06C
Postmark: Apr 12,94 12:40 PM   Delivered: Apr 12,94 12:40 PM
Status: Certified
Subject: SPRAY TECH TOPICS

Comments:
JACK, HERE ARE SEVERAL TOPICS I WOULD LIKE TO HEAR DISCUSSED AT THE KANSAS CITY MEETING IN JUNE. I AM NOT OFFERING TO LEAD ANY DETAILED DISCUSSION OF THESE TOPICS, RATHER THEY ARE AREAS THAT I WOULD LIKE SOME HELP WITH AND HOPE SOMEONE, SOMEPLACE HAS A FEW ANSWERS OR SUGGESTIONS.

-------========X========-------

Jack, here are some topics I would be interested in hearing discussed at the Kansas City meeting in June.

Spray drift - The questions (demands for no deposition of pesticides, even biologicals, in sensitive areas) seem to be accelerating. It might to helpful for someone to produce a generalized paper or brochure discussing drift, factors affecting it, consequences, minimization techniques, model runs showing deposition over distances from the release source under a variety of conditions. Would also be helpful for Bacillus thuringiensis to have data relating effects of deposition (drops/surface area, volume/surface area, IU/surface area) to consequences to lepidoptera. We are trying to deal with some people who appear to be unwilling to accept any degree of risk to non-target organisms from pesticide exposure.

Computer assisted spray block design - I am not a computer person but I believe the capability exists to use computers to assist in design of aerial spray blocks in mountainous terrain. Factors of elevation, aspect, slope percent, and vegetation all need to be accounted for in spray block configuration for treatment effectiveness, efficiency, and safety. What is the state of technology?

Navigation in mountainous terrain - What is the utility of GPS for aerial application in mountainous terrain where contour flying may be common practice? Are existing commercially available GPS systems really operational? Have the levels of pest suppression increased (more kill) where GPS has been used?

Comparison of drop size distributions from fast flying airplanes with hydraulic nozzels and rotary atomizers - I suspect this information already exists somewhere. I have just been too lazy to dig it out. Is there a meaningful difference in the spray drop size distribution for BTK released from airplanes flying at 125+ MPH equipped with hydraulic nozzels or rotary atomizers? What are we buying, besides higher application costs, by specifying airplanes must be equipped with rotary atomizers? Is there an application speed at which the size distributions between the two nozzels types becomes operationally insignificant?

Application pilot training - What training opportunities do application pilots have to develop skills to successfully spray pesticides over forests? Is there training provided by the private sector somewhere?

Economic analysis of non-commodity values - Increasingly the reasons for pest suppression activities have more to do with protecting values that traditionally have not been marketted, thus it is difficult to establish the rate of return on investments made for protecting these resources. Existing Forest Service policy calls for economic analysis of all pest suppression activities funded with Forest Pest Management funds. What opportunities exist for doing meaningful economic analysis where traditionally marketted resources are not the issue? Can we use "opportunity costs of the best foregone alternative" namely timber harvest as a surrogate?

Application pilot evaluations - It has been my experience that contractors tend to exaggerate (LIE) about the experience of their application pilots in spraying forests. It would be helpful if the Agency had a system for rating the

performance of application pilots and tracking pilots' qualifications. Our Aviation and Fire Management personnel pay quite close attention to this for pilots used to transport agency personnel and who fly fire missions. Our missions require as much skill and experience. Our application contracts spell out the experience factors we want. We should not allow contractors to bamboozle us with inflated claims of experience.

Video of forest spraying - We need to have lots of video showing forest spraying, good and bad, to use for training purposes.

Performance of spray aircraft - It would be helpful to have a library or reference of some type that relates the spray performance of spray aircraft from an operational perspective. For example what are the pros and cons of aircraft models such as the Hiller-Soloy, Hughes 500C, Dromader M-18, DC-7, etc. I would include spray patterns from characterization runs, manuverability, dependability, any form of subjective assessments that seem to have some basis in fact.

Karl Mierzejeski
Pennsylvania State
University

PENNSTATE

1855

FAX TRANSMISSION SHEET

TO:	Jack Barry
FAX NO:	(916) 757 8383
FROM:	Karl Mierzejewski Pennsylvania State University, University Park, PA 16802, USA
FAX NO:	(814) 863 4439
TEL NO:	(814) 865 1021
DATE:	27 June, 1994
PAGES:	1 to follow

Dear Jack,

I enjoyed the meeting in KC; as always it brought a lot of key people from all the different groups with responsibilities in aerial application. Here is the draft of my meeting report. I have kept it brief, as the study on which I reported is not complete. I will send the final copy by mail, or I can e-mail it to you if we establish communications.

I forgot that I had scribbled down your e-mail magic number on the inside of my hand, and by the time I remembered to look, I had already washed my hands several times, and the key information had disappeared.

So please e-mail or fax it to me. My Internet address is Karl_Mierzejewski@AGCS.CAS.PSU.EDU and my fax number is (814) 863 4439.

McManus's address for outsiders is FSWA/S=M.MCMANUS/OU=S24L07A@MHS.ATTMAIL.COM. Reardon's is identical except for his name and uses an '8' in place of the '7'. So that central part seems to be the key.

As ever,

Karl

Sent your E-mail address to Karl. 6/27/94 Pat

FSWA/S = J. BARRY/OU = RØ5H@MHS.ATTMAIL.CO

National Spray Model and Application Technology Steering Committee

PSU Report

Karl Mierzejewski

The Pennsylvania State University Aerial Application Technology Laboratory (AATL) performed a field study to measure off-target spray drift of malathion as part of an Environmental Impact Statement (EIS) for the Southeastern Boll Weevil Eradication Program. As well as the field study, the contract for APHIS required that the Forest Service spray deposit model FSCBG be compared with the field data in order to test the utility of using the model in future predictions of spray drift. The field trials were performed near Bainbridge, GA in October 1992, using an APHIS Agtruck to do the application. Flat card collectors were used to measure spray deposit, and rotorod-type collectors and suction samplers were used to measure the drifting portion of the spray cloud. Sample analysis using GLC was performed by NMRAL (the APHIS pesticide residue analysis lab) and PSU. A total of fourteen runs were performed under a wide range of weather conditions. The field data and conclusions have been presented to APHIS in a final report.

At the time of the meeting in Kansas City, only about half of the fourteen runs had been compared with FSCBG modeling runs. Version 4.2 of FSCBG was used for most of the modeling, and currently version 4.3 is being used. In keeping with APHIS requests, the modeling is being performed in a manner which would show the closest possible match of field data with simulated data. The many different options available in FSCBG are therefore being tested. The brief report that follows details the findings so far. No statistical analysis comparing the field data with the simulation data has yet been performed.

It was found that selecting a total Gaussian model for both near wake and far wake drift more closely matches the field data than a Lagrangian near wake model (such as AGDISP) which transitions to a Gaussian far wake model. This is in accordance with a study performed by Richardson in New Zealand where a low application height was used. The current study used an application height of 1.5m. The Gaussian model shows a close fit of the data in some of the runs analyzed to date, and a less close fit with others. There does not appear to be correlation with any atmospheric parameters such as stability, wind speed and turbulence, with accuracy of the match of field and simulated data.

Total flux was measured at three levels in the field to a height of 8 meters above ground. When these flux values are averaged for the vertical distance, and compared with total flux calculations calculated from the dosage data of FSCBG simulations, a close correlation is obtained between the field data and the simulations. In most cases the Lagrangian (AGDISP)/Gaussian combination gives the most accurate results.

For the malathion droplet spectrum, which was measured at the NMSU wind tunnel using a Malvern spectrum analyzer, there seems to be little difference in the far wake deposition and drift simulations whether a 16 size class spectrum or a 100 size class spectrum is used as input for the model. All simulations of deposit along a grid with a 20 meter spacing for a 1,000 meter distance produced a deposit minimum at the 500-600 meter point with a subsequent increase in deposit downwind from the source. This ‘dip’ was beyond the distance that was sampled with flat plate collectors in the study. The pure Gaussian simulations show a reduced dip in the deposition values when compared with the Lagrangian/Gaussian simulation.

Brian Richardson
Forest Research Institute
New Zealand

REPORT FOR THE NATIONAL SPRAY MODEL STEERING COMMITTEE

USE OF FSCBG IN NEW ZEALAND

Brian Richardson

RESEARCH

1. Spray drift from orchard airblast sprayers and tree shelter belts as barriers to drift

Earlier this year a trial protocol was developed for measuring spray drift from an orchard airblast sprayer with collaboration between NZ Forest Research Institute (NZ FRI), NZ Agricultural Engineering Institute (NZAEI), and the USDA Forest Service (USDA FS). The substantial input from the USDA FS (via Harold Thistle and Milt Teske) is a result of an increased level of collaboration between the USDA FS and NZ FRI.

The objectives of the trials were to:

- Characterise orchard airblast sprayers.
- Measure the effectiveness of shelterbelts on reducing drift.
- Provide drift data to the USDA Forest Service for further development of FSCBG

An initial trial was completed in early autumn. The basic design was to release spray from an airblast sprayer along a single line, upwind of a shelterbelt. Airborne spray flux and ground deposition were measured both upwind and downwind of the shelterbelt using Rotorods, suction samplers, and steel plates placed on the ground. The shelterbelt was characterised using photographic and video techniques in combination with image analysis, and with the LiCor Plant Canopy Analyser.

The greatest problem (as usual with this type of experiment) was waiting for appropriate meteorological conditions, especially wind direction, before the autumn leaf fall. Although the weather was never ideal, some initial data was successfully gathered and this is currently being processed. The intention is to continue with this collaborative work next summer.

2. Spray deposit variation

Work on the analysis of spray deposit variation following aerial herbicide application in forestry is ongoing (see report submitted at the last meeting). The initial analysis involved the use of field data and model simulations to determine the magnitude of spray deposit variation and important parameters that contribute to this. More recently, information on deposit variation has also been linked to general models of herbicide/weed dose-response and weed/crop competition, so that the cost-benefit of reducing deposit variation (e.g. by using GPS) can be evaluated. Specific data for the dose-response and competition models was of low quality or not available. However, with this approach, a number of scenarios were developed to examine the effect on crop growth of deposit variation in situations with "idealised" weeds of different competitive abilities and using "herbicides" of different effectiveness (see Abstract report)

ECONOMIC AND BIOLOGICAL IMPLICATIONS OF HERBICIDE SPRAY DEPOSIT VARIATION IN FORESTRY

Brian Richardson, Kylie Miller, and John Ray

NZ Forest Research Institute, Private Bag, Rotorua

31.5.94

ABSRACT

To determine the biological implications of herbicide spray deposit variation, models of herbicide deposition were linked to models that describe the response of the weed to the herbicide and the response of the crop to various levels of weed control. In a typical forest herbicide application, less than 20% of the sprayed area is likely to receive a herbicide dose within 10% of the application rate. The average coefficient of variation is 43%, but values higher than 70% have been recorded during operational field trials. The effect on radiata pine growth of these levels of deposit variation was determined assuming a weed species of high or low competitive ability and for a variety of herbicide/weed dose-response curves. In the worst-case scenario (i.e. a highly competitive weed species that is very sensitive to the herbicide dose at the nominal application rate) growth losses of 13, 15.5, 17.5, 20.5% were respectively associated with deposit variation levels (coefficient of variations or CVs) of 10, 30, 43, and 70%. Thus the greatest effect on growth occurs when the CV of deposition goes from 0 - 10%. It is unrealistic to reduce operational CVs below about 30%, and the growth gain in reducing the level of variation from 43 or 70% to 30% is only 2 and 5%, respectively, at age 2.5 years.

At age 2.5 years, the growth gain in reducing CVs from 70% to 30% is equivalent to a gain in net present value(NPV) of about $/ha 23-25. This calculation assumes that the time advantage at age 2.5 years remains constant until rotation age. In reality, the time advantage would likely to increase with buddleia as a competitor, so these are likely to be minimum values for gain in NPV. The gain in NPV is the amount of money that can be spent on reducing deposit variation within the limits discussed above.

TRAINING AND TECHNOLOGY TRANSFER

1. Course in NZ

In February this year, the second New Zealand FSCBG training course was held at the Forest Research Institute in Rotorua. Ten people attended the course (four forest managers, two researchers, two pilots, and two chemical company representatives) including two from Australia. The course was run over 3 days with instruction from Milt Teske and help from Harold Thistle, John Ray and myself. The course was well received, and its obvious success was, to a large extent, due to the marathon efforts of Milt Teske. The increasingly user-friendly nature of the software was also demonstrated by the fact that even the students with little computer experience soon mastered the basics of FSCBG. A number of "bugs" in the beta 4.3 version were found and a lot of useful suggestions were made by students.

There are now 16 registered FSCBG users in New Zealand. This is probably the highest per capita rate of users anywhere in the world, including the USA. The high level of interest in FSCBG in New Zealand is driven through the forest industry. Plantation forests in New Zealand are highly dependent on intensive management practices, including the application of pesticides, predominantly herbicides. The forest industry has for many years taken initiatives to ensure that they are using the best possible application practices for both environmental and economic reasons, and use of models such as FSCBG is one important approach. The model is being used by the forest industry to provide general guidelines for designing spray operations and for minimising drift.

It is hoped that eventually another course will be held in New Zealand to cater for Australasian needs.

2. Proposal for manual on recommendations for minimising drift

FSCBG is a powerful and increasingly user-friendly tool. In New Zealand, it is used predominantly for issues relating to spray drift. Even though a significant number of people have been trained to use the model it is still not accessible to most. A major concern is that the "knowledge" contained within, or that can be derived from, FSCBG is still not easily available to the spraying community (either managing, regulating or applying sprays). We cannot realistically expect **all** of the pilots, foresters, contractors etc. who are involved with spraying to learn how to use the model, and to remain sufficiently familiar with it so that they can use it at irregular intervals. It is therefore essential to present this information in another form.

The "What's New in Forest Research" publication, produced by NZ FRI in 1993, is the type of publication required, but this article only presented information on how to reduce drift when there is an extreme drift hazard. There are many instances when these recommendations would not be the best spraying method. A major task over the next 12 months is to develop some other form of publication for transferring the technology and "knowledge" relating to spray drift, embedded in FSCBG. Two main steps are being considered.

1. Development of an easy-to-understand manual with simple diagrams that illustrate the importance of various spray parameters in terms of spray drift. The manual will be developed using data from FSCBG model runs. However, from our experience, general

users find it difficult to interpret graphical representations of spray drift presented using normal methods. For the manual, new forms of presentation have been developed that operational people find easier to understand. The manual will demonstrate the effects of important variables on spray drift and operation productivity and will assist managers to develop appropriate spraying prescriptions.

2. A second step would be to use the information generated from preparing the manual, plus additional FSCBG runs, to produce a more complex, decision support system (DSS). The decision support system would be either presented as computer software or as a book/manual. With this approach, the objective would be to guide managers and operators through the decision making process, helping them select optimal treatments for a given scenario. A PC-based DSS to assist with spray application problems would be linked to a Vegetation Management DSS that NZ FRI and its partners have already developed. At present, this system selects the best chemical or non-chemical treatment to manage vegetation on any site, but it has only limited information on herbicide application techniques.

While neither of these approaches can replace FSCBG, it is hoped that they will make information derived from the model more readily available to users.

3. International Conference on Forest Vegetation Management

In March 1995, the NZ FRI is hosting the second International Conference on Forest Vegetation Management (see Jack Barry for more information). One of the three major themes to be addressed is "Regulatory, Training and Management Support Systems". Contributions are invited on topics relating to technical and training issues with FSCBG and associated models, as long as the subject relates to vegetation management issues. For more information, contact either Jack Barry or Brian Richardson.

HERBICIDES USE AND REGULATION IN NEW ZEALAND'S PLANTATION FORESTS

Brian Richardson and John Ray

NZ Forest Research Institute
Private Bag, Rotorua, New Zealand

SUMMARY

Plantation forests in New Zealand are intensively managed to achieve and sustain high levels of productivity. Broadcast weed control, generally using herbicides, has been a traditional practice to ensure high crop growth rates and survival after planting. More recently, the concept of vegetation management has been adopted and the focus has been on developing regimes of operations to achieve management objectives. These regimes include treatments that add new vegetation (generally grasses and agricultural legumes) to sites, as well as both broadcast and selective weed control using herbicides.

A wide range of herbicides are available for control of woody and herbaceous vegetation in both pre- and post-plant situations. Aerial spraying is still the predominant method of aerial herbicide application, but there is increasing emphasis on selective spot treatments that have the advantages of reduced chemical use, reduced costs, and generally less potential for spray drift. Aerial application simulation models such as FSCBG have an important role in improving the efficiency and reducing the potential for spray drift from aerial herbicide applications. Herbicide selection decision support systems are likely to have an increasing role in helping to optimise the use of herbicides.

Regulation of herbicide use in New Zealand is currently covered by a wide range of laws. However, a process of rationalisation is underway, that will both simplify and tighten up the legislation. The most important new development is the introduction of the Resource Management Act (RMA). Under the RMA there will effectively be three levels at which controls can be set on herbicide use. The Government (Ministry for the Environment) will set the basic rules covering such things as minimum water and air quality standards; Regional Councils (there are 14 Regional Councils covering the whole of New Zealand) must adopt centrally defined standards but are empowered to increase their stringency within their area of control; District Councils (there are several districts within each region) can only increase standards set by their governing regional council. The forest industry has already established a Code of Practice that includes all areas of pesticide use, and requires that all employees involved with any aspect of pesticide use, undergo training.

INTRODUCTION

New Zealand is a land of 26.7 million ha, spanning latitudes of approximately 47° to 34° in the Southern hemisphere. Almost 28% of the land area is covered in forest including 1.2 million hectares of plantations (NZFOA, 1991), the majority being privately owned. Plantation forestry is synonymous with radiata pine (*Pinus radiata* D. Don), which is grown on more than 1.1 million ha of the plantation area. Within the radiata pine forests, high levels of productivity are often achieved and maintained through intensive management practices. Out of these practices, vegetation management plays a critical role in early stand establishment and has a large influence on initial, and sometimes later, growth rates. Following a brief introduction explaining the importance of, and background to vegetation management ipractices this paper presents a detailed discussion on the use of herbicides in New Zealand's plantation forests.

Vegetation management versus weed control

In the past, all vegetation on a site, other than the crop trees, has generally been categorised as undesirable and therefore "weeds". Thus, sophisticated methods of weed control were developed, generally using herbicides, and were applied broadcast (i.e. total weed control) to most sites as a matter of course. However, more recently there has been a philosophical shift in terms of managing non-crop plant species and the mentality of "weed control" has been replaced by the concept of forest **vegetation management**. The original concept of vegetation management was to change the focus from that of simply removing all non-crop species i.e. weed control, to that of reducing the **influence** of weeds (Walstad and Kuch, 1987). With this outcome in mind, the research emphasis must also shift from simply developing tools to remove weeds, to understanding the effects of non-crop vegetation on crop growth and long-term site productivity.

The concept of vegetation management also acknowledges that the focus must be on the development of regimes to manage the site over a long period. A weed control treatment in forestry is always a short term option (non-crop plants will eventually establish and occupy a site unless the treatments are endlessly repeated) therefore emphasis must be on the development of sequences of operations or **regimes** that achieve the ultimate management goals. In practice, vegetation management regimes comprise operations that result in vegetation removal (often selective weed control) and sometimes also vegetation additions. The aim is to manipulate the natural succession of the site so that it follows the most favourable sequence for the management objectives. However, herbicides are still the primary method used in the development of vegetation management regimes.

Why manage vegetation?

There are many reasons, summarised below, why vegetation management is practiced in New Zealand forestry.

1. *Reduce interspecific plant competition*

Many studies have demonstrated large growth gains following removal of plant competitors (Richardson, 1993). Thus, the primary aim of vegetation management is usually to "channel site resources (i.e. light, water, and nutrients) into the crop species rather than non-commercial species" i.e. reduce competition between the trees and the other plant species, to maximise crop growth and survival.

2. *Land clearance*
Prior to the 1970s, most plantations were established on virgin and cutover native forests (Boomsma, 1982), therefore much of the vegetation management was focussed on clearing sites of existing native shrub and hardwood vegetation to allow the planting of tree seedlings. However, more recently the trend has been to establish forests on flatter, more fertile pasture land, and large scale conversion of native forests to plantation forests is rarely practiced (NZFOA, 1991).

3. *Microclimate modification*
Vegetation management is also practised to modify the seedlings' thermal environment. In areas prone to out-of-season frosts, complete vegetation removal is practised for up to 2 years after crop planting to raise the air temperature close to the ground and decrease the likelihood of frost damage to radiata pine (Menzies and Chavasse, 1982).

4. Fire hazard reduction and stand access
Sometimes vegetation management is undertaken for fire prevention or reduction of fire hazard (Burrows et al., 1989) and/or to improve stand access for tending operations such as pruning and thinning (Balneaves, 1981; Zabkiewicz and Balneaves, 1984).

4. *Pre-emptive weed control*
Weed control is sometimes carried out in areas and roadsides adjacent to plantations to prevent the development of future problems from invasive species.

5. *Oversowing*
In contrast to the need for vegetation removal as described above, vegetation management in New Zealand sometimes involves establishing various non-crop plant species. Of particular interest is the establishment of N-fixing species (Gadgil et al., 1984) to improve site/crop nutrition. Other reasons are to provide fodder in agroforestry systems, to establish a "benign" or easily controlled ground cover that will help to exclude more severe woody competitors, and to reduce erosion.

VEGETATION CONTROL USING HERBICIDES

Traditional means of controlling vegetation include the use of chemicals, mechanical treatments, manual cutting, and fire, although there are an increasing number of other options. However, herbicides have by far a dominant role in New Zealand forestry. A detailed discussion of the role of herbicides and regulations governing herbicide use follows. For more information on alternative methods of vegetation control in New Zealand see Richardson (1993).

Results from a recent survey (Boomsma and Hunter, 1990) illustrate the dominant role of herbicide treatments for vegetation management. Many stands have more than one treatment and very few have no herbicide treatment. Although herbicides play a critical role on most sites, the quantity of chemical used has actually dropped over recent years (MacIntyre et al., 1989) probably because of improved spray formulation or application methods (Zabkiewicz, 1992).

Prior to the 1970s commonly used herbicides included phenoxies (2,4-D, 2,4,5-T, MCPA) picloram, and desiccants such as AMS, paraquat, diquat in addition to sodium chlorate (Chavasse, 1976). These chemicals were used in the conversion of indigenous native forests, and to release newly established plantations from a wide range of native and exotic woody species (Boomsma, 1982). In the early 1980s, phenoxies, especially 2,4,5-T were predominant (Turvey, 1984). There was much concern at the withdrawal of 2,4,5-T in the mid-1980s because of its importance to the forest industry, but with suitable additives, other chemicals such as glyphosate, metsulfuron, clopyralid (especially for some legume species) and triclopyr (often in mixture with picloram) have taken over its function. Mixtures of herbicides, such as glyphosate plus metsulfuron are also used. Of particular value has been the development of adjuvants, especially organo-silicones such as Silwet L-77 (Stevens et al., 1988), which increase the uptake and efficacy of certain herbicides into hard-to-kill scrub weeds and some perennial grasses. Of the chemicals most commonly used in woody vegetation management control, only hexazinone, clopyralid and triclopyr (low rates) are suitable for broadcast post-plant treatments over radiata pine (Balneaves and Davenhill, 1990).

By the early 1970s, both soil residual and foliar applied herbicides were commonly used for grass and herbaceous broadleaf competition control (Davenhill, 1971). Herbicides included triazines, dalapon, and amitrole (Preest and Davenhill, 1969; Boomsma and Karjalainen, 1982). Glyphosate, available in the 1970s, proved to be excellent for grass control, and hexazinone provided good control of grass and perennial pasture weeds such as sorrel, paspalum, and cat's ear (Boomsma, 1982). Haloxyfop and quizalofop-p-ethyl are useful for selective grass control, including pampas, and clopyralid for broadleaf and herbaceous legume control with terbuthylazine a useful addition for residual activity. Radiata pine is tolerant to most of these chemicals, which can be used in both pre- and post-plant situations, with the notable exception of glyphosate. However, glyphosate has been used in releasing situations using a knapsack sprayer to kill vegetation surrounding the seedlings.

To help managers select the most cost-effective and safe herbicide for each situation a PC based Vegetation Management Decision Support System has been developed (Mason, 1991; Mason et al., 1992). The first version was purely a herbicide selection system; however, the most recent version incorporated non-chemical weed control methods. The ultimate goal is to have the system select the optimum sequence of treatments (i.e. the regime) necessary to meet the management objective.

To summarise, chemical weed control has proven to be economic, it can be applied on rough, steep terrain using aircraft, and produces large growth responses (Boomsma, 1982). Because of environmental concerns however, there is continued pressure to seek alternatives and reduce reliance on chemicals. Although herbicides are extremely important to successful forest establishment and early growth, vegetation must usually be controlled as part of a regime of which herbicides are only one component. More information on herbicide use and weed control in New Zealand plantation forests is available in a recent publication (Davenhill et al., 1994).

HERBICIDE APPLICATION METHODS

Aerial application

Aerial herbicide application in New Zealand was becoming popular by the mid-1950s, (Currie, 1959). At this time, environmental issues and concerns did not occupy the prominent position they do today. Nevertheless, spray drift from herbicides was regarded as a real concern. Ferens (1955) noted that,

"... these chemicals in the wrong hands or with incorrect application can be dangerous; the avoidance of light winds is essential for both good control and for reducing the damage to neighbouring properties. Damage has been reported as much as 15 miles from the site of spraying in unfavourable conditions."

Today, aerial application is the most extensively used method of herbicide spraying in New Zealand (Turvey, 1984). This technique has advantages of high productivity (area sprayed per hour) even on steep, broken, slash-covered terrain, inaccessible to ground sprayers. Helicopters are used almost exclusively, the Bell Jet Ranger being most common, and smaller numbers of others including Hughes 300 and 500, Hiller 12E, Aerospatiale Lama and Squirrel. Advantages of helicopters over fixed wing aircraft are that they are more precise in steep, broken terrain, they can fly slower and lower, and can follow contours more readily (Ray, et al., 1992). Although more expensive per hour, helicopters can be more productive than fixed wing aircraft of comparable size, depending on factors such as relative load capacity, location of helipad/landing strip, application rate (Ray, et al., 1992).

Drift reduction is always a major concern and as such, sprays are generally applied using what are considered to be "low-drift" nozzles. Because of the large droplets produced by most low-drift nozzles, there has always been the trend to use high application volumes (usually between 200-350 litres/ha) to ensure good coverage is achieved on hard-to-kill brush weeds. However, over recent years there has been a gradual trend towards lower spray volumes (generally between 50-150 litre/ha). Although this gives a reduction in spray coverage on the target plant, superior chemicals and adjuvants clearly compensate for this factor, and there is the added benefit of increased productivity (area sprayed per hour). In terms of hectares of forest land sprayed, foaming nozzles are probably the most common nozzle, followed by conventional D8-45 nozzles and then D8-46 nozzles. Results of recent trials have confirmed that foaming nozzles significantly reduce drift potential compared to the D8-45, so it is likely that they will continue to be used. However, in situations where drift control is paramount, nozzles which will reduce drift even further would include D8 straight back or Raindrop (Delevan Co.) nozzles. The half-overlap flying technique is generally used to reduce coefficients of variation. On flat sites, some form of flight line marking (e.g. flagmen) is not uncommon, but this is often impractical on steeper terrain. The potential of GPS as an electronic aid to increase the precision of herbicide applications is under investigation.

To identify techniques to minimise herbicide spray drift, a considerable effort has gone into applying and validating the FSCBG spray application simulation model (Teske et al., 1993) to New Zealand conditions. The model has been used to provide general recommendations for minimising spray drift, and for selecting spray equipment and methods for maximising productivity. It has proven to be an excellent training tool (there are 16 trained users in New Zealand, with a further two from Australia having been through the New Zealand training

course), and it is hoped that using the model operationally will be accepted by regulators as evidence of applying "best practices".

Ground application

On flatter terrain, largely free from logging slash and with easy access, ground based herbicide application techniques using vehicle-drawn booms or hand-held sprayers are viable methods, particularly on smaller blocks. Vehicle mounted boom sprayers treat 1-2 m wide strips along planting lines (Flinn and Fagg, 1984; Balneaves, 1987). Spot treatments reduce costs still further (Davenhill, 1988; Davenhill et al., 1992; Flinn and Fagg, 1984; Glass, 1985) and also have the advantages of reduced environmental impact and less drift, particularly with the use of granules. "Spots" usually comprise circles of radius 0.5 - 0.6 m centred on each young tree that is treated. Originally, herbicide spot treatments were applied with knapsack sprayers (Davenhill et al., 1992), but these have largely been replaced with "spot guns" (Porter, 1979). More recently, the "Weed-a-Metre" has been developed for spot-application of herbicide granules (Davenhill et al., 1992). Although granular herbicide formulations are more expensive, the Weed-a-Metre has the advantage over spot guns in terms of higher productivity (Davenhill and Hall, 1988), lighter weight, and no water or chemical mixing is required. The area of forest land suitable for spot applications is increasing with the trend towards oversowing forest sites to provide an herbaceous (grass and broadleaves) ground cover, consequently the importance and interest in this method of application has also increased.

LEGISLATION COVERING THE USE OF HERBICIDES

At present, there is a bewildering array of Acts and regulations covering different aspects of pesticide use in New Zealand. However, with the introduction of the Resource Management Act (RMA) in 1991, a process of rationalisation has begun. Pesticide regulations will soon be covered by fewer pieces of legislation and will be much stricter than previously. Although this reorganisation is not completed and many of the old laws are still in place, the following summary focuses mainly on the RMA because of its future central role in pesticide legislation.

Resource Management Act

The broad purpose of the RMA is to promote the sustainable management of natural and physical resources. "Sustainable management" means managing the use, development, and protection of natural and physical resources in a way, or at a rate, which enables peoples and communities to provide for their social, economic, and cultural well-being and for their health and safety while-

(a) Sustaining the potential of natural and physical resources (excluding minerals) to meet the reasonably foreseeable needs of future generations; and

(b) Safeguarding the life-supporting capacity of air, water, soil, and ecosystems; and

(c) Avoiding, remedying, or mitigating any adverse effects of activities on the environment.

This Act has widespread implications for many aspects of forestry including herbicide use. The RMA specifically prohibits the discharge of contaminants into water, or onto ground in such a way that the contaminant or its breakdown product enter water. Contaminants can be discharged with the appropriate consent but this would never be given for pesticides. There is provision in the Act for pesticides to be applied over "productive land", provided that pesticide application is not specifically prohibited in the Regional Plan (see below for explanation of Regional plan). Included in the RMA is provision to establish a Hazards Control Commission which will operate under the Hazardous Substances and New Organisms Act. This legislation, which was to be introduced in 1993, will ultimately replace existing acts and regulations governing the use of pesticides. Due to the complexity of preparing this piece of legislation, the 1993 deadline has not been met!

The RMA allows for controls to be imposed at three levels;

(a) **The Government** (Ministry for the Environment) will set the basic rules governing such things as minimum water and air quality standards (the RMA provides powers to control the discharge of hazardous substances into air , soil, and water).

(b) **Regional Councils** (there are 14 Regional Councils covering the whole of New Zealand) must adopt centrally defined standards, but are empowered to increase their stringency within their area of control. Regional Councils are responsible for law enforcement.

(c) **District Councils** (there are several districts within each region) also can only increase standards set by their governing regional council.

Regional and district councils are required to produce plans for their areas and have the power to restrict or even prohibit the use of any, or specific pesticides within certain areas. Zoning may prove to be the most effective mechanism for isolating pesticide application from the general population. The Act does not restrict pesticides to agricultural or horticultural land, but does prohibit their use in a way that would contaminate water. The councils are also responsible for the enforcement of regulations. Individuals or groups can apply for an abatement order if the discharge/application is deemed to be "noxious, dangerous, offensive, or objectionable to such an extent that it has, or is likely to have, an adverse effect on the environment". This provision seems to provide a means of possibly restricting the use of pesticides, as many will have an adverse effect on at least some part of the environment. Abatement orders do have the potential to restrict the use of pesticides, but if the use is included in the regional or district plan it may not be so easy to stop.

The New Zealand forest industries response to the Act has been to liaise with regional and district councils at the stage of plan development in an effort to make planners aware of how and why pesticides are used, the quantities applied, and the precautions taken to limit adverse

effects both on and off site. This approach seems to have been successful and it is likely that the councils will take a "best practices" approach, rather than specify clearly defined limitations on application methods. In addition, the forest industry has voluntarily developed a Code of Practice for the use of pesticides and is ensuring that its staff are fully trained. The conditions set out in the Code of Practice are not mandatory but there is a precedent in New Zealand law to incorporate a code or parts of it in regulations to make it mandatory. Alternatively, the Regional Council could include the Code or parts of it in its Regional Plan and compliance with those sections would again become mandatory.

Other considerations

Another recent law with major implications for the forest industry is the Health and Safety in Employment Act of 1992. This requires all employers to identify all hazards associated with any particular operation and then eliminate, isolate or minimise the hazard. It requires the employer to notify employees of the hazards and to provide the appropriate safety equipment/clothing and training to enable them to carry out the operation safely. The employee must use the safety equipment provided. Failure by either parties to fulfil their obligation under the Act, render both liable to heavy penalties. Once again, the response of the forest industry to this Act has been to place an increased reliance on training all employees and contractors to a national certification standard and to ensure good supervision is available.

The regulatory emphasis has, to date, focussed on voluntary observation of standards of good practice. However in a recent report to the Parliamentary Commissioner for the Environment entitled "Management of Agrichemical Spray Drift" it was recommended that:

(a) a compulsory system of registration and training of applicators should be established
(b) codes of practice should become mandatory
(c) minimum standards for equipment should be set
(d) records should be kept of pesticide misadventure with the power to deregister applicators if it is shown that they have failed to follow the code of practice.

If these recommendations are accepted and incorporated into law, they should not have a big impact on the forest industry because they have essentially already implemented these measures.

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Nick Woods
The Center for Pesticide
Application and Safety

Head of Department Associate Professor Ken Rickert

THE CENTRE FOR PESTICIDE APPLICATION
AND SAFETY (C-PAS)
Director: Nicholas Woods

THE UNIVERSITY OF QUEENSLAND
GATTON COLLEGE
Lawes Qld 4343 Australia
Telephone (074) 601 281
International +61 74 601 281
Facsimile (074) 601 283
Email nwoods@jabiru.uqg.uq.oz.au

NATIONAL SPRAY MODEL AND APPLICATION TECHNOLOGY STEERING COMMITTEE

Kansas City, MO, June 22 1994

Summary - The Potential for FSCBG Validation - Australia

Nicholas Woods
Director
The Centre for Pesticide Application & Safety
The University of Queensland Gatton College

The Centre for Pesticide Application & Safety is a national scientific research and training group located at the University of Queensland Gatton College, near Brisbane Australia, which provides a wide range of research and consultancy services to industry and government in pesticide application technology. Equipped with a wide selection of specialist sampling and analytical equipment, research and training support programmes are provided in agriculture, public health (eg mosquito control) and forestry.

A major national research programme is currently underway in Australia entitled "Minimising the Impact of Pesticides in the Riverine Environment Using the Cotton Industry as a Model." Within this programme the Centre has the responsibility for investigating the aerial transport of pesticides in the cotton industry. In particular the ULV and LV aerial application of endosulfan is being targeted. The programme which commenced during the 93/94 growing season has the following components:

- An aircraft testing and calibration phase: Both Turbine and piston engined aircraft are being pattern tested using artificial targets and cotton canopies

- Nozzle performance: The droplet size generated by nominated cotton insecticides is being determined in the laboratory using Malvern 2600 laser diffraction equipment. The performance of Micronair and selected hydraulic nozzles is being evaluated.

- Volatilisation: Post application volatilisation and deposition in water is being assessed using a series of water filled trays and air samplers placed strategically around commercial cotton fields to quantify residue levels.

- Field measurement of pesticide recovery: Using mobile drift measuring towers, fluorometry and gas chromatography, profiles of spray deposits moving away from both commercial spray activities and from controlled experiments are being measured. Deposit curves from single passes of aircraft have been measured in the canopy and from artificial targets. Towers and wires have been used to quantify drift at short and medium distances (up to 600 metres)

The data base being collated will be analysed and tested against models such as FSCBG. Within 3 years the project aims to provide management strategies to industry to enable productive and sustainable cotton production in the riverine environment.

Of interest to the Centre is work being undertaken elsewhere to evaluate FSCBG in field crop canopies such as cotton and the model's sensitivity to describing the performance of ULV pesticides. The data being collected in the Australian aerial application programme should allow some detailed validation of the models.

The future of aerial application technology in Australia will depend in part on the success of this programme. Linkage of simulation models with DGPS systems and computer support spray management packages is being canvassed.

In other research, the coverage and drift profile of orchard sprayers is being determined. The applicability of FSCGB in such scenarios deserves investigation.

Finally there are increasing pressures to use models such as FSCBG in evaluating spray drift occurrences and damage. Comments from the committee on the scientific and legal implications of this trend would be valued.

THE CENTRE FOR PESTICIDE APPLICATION & SAFETY
C-PAS

THE UNIVERSITY OF QUEENSLAND GATTON COLLEGE

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- Spray Nozzle Evaluation
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- PESKEM® PC for Windows™
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Contact the Centre if you have any application technology related questions or require any further information on the wide range of services available.

Contact Information:-

The Director
The Centre for Pesticide Application & Safety, (C-PAS)
The University of Queensland Gatton College
LAWES
Queensland, 4343, Australia

Tel: 074 601 293 Fax: 074 601 283
Email:- nwoods@jabiru.uqg.uq.oz.au

THE UNIVERSITY OF QUEENSLAND
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THE CENTRE FOR PESTICIDE APPLICATION & SAFETY
C-PAS

The University of Queensland Gatton College

INFORMATION BROCHURE
and
SERVICE DIRECTORY

Your guide to consultancy services in Pesticide Application Technology

The Centre for Pesticide Application & Safety (C-PAS)
The University of Queensland Gatton College

The Centre for Pesticide Application and Safety is a national scientific research and training group located at the University of Queensland Gatton College, near Brisbane, which provides a wide range of research and consultancy services to industry and government in pesticide application technology. The Centre comprises of some ten staff made up of research, extension and technical officers from the University and the Queensland Department of Primary Industries.

Equipped with a wide range of specialist sampling and analytical equipment and utilising facilities located at Gatton College, research and training support programmes are provided in agriculture, public health (eg mosquito control) and forestry.

Typical services available include:-

(1) Testing and **calibration of agricultural aircraft**, (encompassing application of both solid and liquid products).
(a) Equipment evaluation (incl. DGPS) and drift analysis
(b) Provision of fully serviced calibration analysis.
Test kits are now available.
(2) Comparative evaluation of **ground rig boom and orchard** spray equipment.
(3) Spray nozzle testing and **droplet size measurement** in the laboratory and under field conditions using a Malvern 2600 laser diffraction analyser.
(4) Assessment of **pesticide recovery** on artificial surfaces such as water sensitive cards
(5) Field studies
(a) establishing the behaviour of agricultural chemical and biological products
(b) researching factors which maximise canopy coverage and **minimise pesticide spray drift.**
(6) The physical analysis of agrochemical formulations and laboratory **rain fastness evaluation.**
(7) The training of personnel in the correct and safe handling, application and distribution of agricultural and public health pesticides through the medium of training **workshops, short courses and seminars**.
(8) Production and maintenance of PESKEM® and now **PESKEM® PC for Windows™**, a national database providing information on all registered pesticides in Australia.
(9) The use and running of pesticide **(drift) simulation models** such as FSCBG.
(10) Publication of industry training technical manuals.
(11) **Consultancy.** The Centre provides specific information and advice on pesticide application and plant protection related matters.

Appendix D

Report - Sub-committee on Meteorology

May 17, 1994

To:
Members of the National Spray Model and Spray Technology Meteorological Sub-committee

Dear Colleagues;

I hope Spring finds you all well. We have had some changes in the organization of this sub-committee since we were together last June in Spokane, WA. Dave Whiteman has resigned the chairmanship of this sub-committee and is off to a sabbatical in Switzerland as of this July. I have been appointed his successor as chairman. Also, Bob Ekblad has retired from federal service and resigned his place on the committee. He is occasionally in touch from his orchard on the lake. On the other side of the coin, I would like to welcome Bob Sanderson of New Mexico State University. I invited Bob to join the committee last week and he has accepted.

While you all have been hibernating over the winter, Dave Whiteman and myself have put together the enclosed rough draft of 'Meteorological Measurements for Spray Drift Modeling'. Please review and return comments to me by August 31. In my opinion, there are three primary concerns regarding this document:

1) I have asked Jack Barry to comment regarding the technical level of this document with respect to the target audience.

2) The document needs illustrations.

3) Are the document scope and subject matter appropriate?

I would appreciate comments on all of these matters as well as a general review. I hope to see many of you in Kansas City in June and we can discuss questions and comments at that time. Otherwise, feel free to call me at 406-329-3981.

Sincerely,

Harold Thistle

DRAFT REPORT

METEOROLOGICAL MEASUREMENTS FOR SPRAY DRIFT MODELING

National Spray Model Advisory Committee
Meteorological Subcommittee

Subcommittee Members:

Dave Miller
Jim Rafferty
Robert Sanderson
Harold Thistle, Chairman
Dave Whiteman

May 17, 1994

OUTLINE

METEOROLOGICAL MEASUREMENTS FOR SPRAY DRIFT MODELING

Meteorological Subcommittee
National Steering Committee - Spray Modeling

1.0 INTRODUCTION

This document provides information on the meteorological measurements needed to run FSCBG, AGDISP and VALDRIFT, three atmospheric dispersion models used to calculate deposition and drift of pesticides from aerial spraying applications.

The report begins with a discussion of the various uses of aerial spray application models, and a description of the three models currently in use. This is followed by a listing of the meteorological measurements needed to apply these models to actual spraying applications, as obtained from the model user manuals. The types of measurements, their frequency, and the number of locations at which the data are needed depends on the purpose of the model application and the particular topography. Several different spraying scenarios are therefore discussed. These scenarios include a small-scale pesticide application in a remote area, a routine pesticide application in an accessible forested area, and a research application. Siting and frequency considerations are then discussed, and illustrated with some sample data sets. Anticipated changes in technology that will lead to new meteorological tools are then discussed. Conclusions and recommendations make up the final section of the report.

2.0 The Spray Models

2.1 Uses of Spray Models

2.1.1 Planning of Operations

Spray models can be used before a field spraying campaign to help with the planning of the field operation, to anticipate operational problems, or to take advantage of special opportunities that will expedite or improve the execution of the spraying campaign.

2.1.2 Operational Decisions

During the spraying campaign, spray models and the real-time meteorological data that drive them can be used to help the on-site spray manager make informed operational decisions. Such decisions include go/no go decisions, determination of the times of initiation and cessation of spraying, and the positioning of equipment and personnel. The data and models can also be used to support operational decisions regarding use of contract spray aircraft and personnel.

2.1.3 Analyze Deposition/Drift

After (or during) the spraying operation the models can be used to estimate the deposition of pesticide on the target area and the transport and deposition of spray onto non-target areas.

2.2 Model Descriptions

2.2.1 FSCBG

The Forest Service Cramer-Barry-Grim (FSCBG) computer model has been developed to allow computer simulations of aerial spraying operations. The model is based on dispersion models originally developed by the U.S. Army ( ). For the past 15 years, the USDA Forest Service has been improving the model for applications in the aerial application of pesticides. The model consists of near-wake transport based on the solutions to aircraft wake vorticity equations (as developed in AGDISP, Section 2.2.2) and a meso-scale dispersion model based on a Gaussian line source approach. The model calculates deposition, canopy penetration and atmospheric concentration. Over the past few years, the FS and Pacific Northwest Laboratories (PNL) have been working on an algorithm to predict the atmospheric transport of aerial sprays in mountain valleys (VALDRIFT, Section 2.2.3). This model should be fully integrated into FSCBG by 1995.

2.2.2 AGDISP

The AGDISP (Agricultural Dispersal) code predicts, as a function of time, the path of material released from a helicopter or fixed-wing aircraft, and deposited on the ground or in a canopy (Bilanin et al., 1989; Teske, 19). To do this, the code tracks groups of similar sized particles or droplets released by the traveling aircraft. The turbulent dispersion of droplets is computed as the group of droplets descends toward the ground, taking account of transport and diffusion in the aircraft wake vortices.

2.2.3 VALDRIFT

The VALDRIFT (Valley Drift) model is an atmospheric transport and diffusion model for use in well-defined mountain valleys (Allwine et al., 1993). It was developed especially for determining the extent of drift from USDA Forest Service aerial pesticide spraying activities. The model is phenomenological - that is, the dominant meteorological processes governing the behavior of the valley atmosphere are formulated explicitly in the model, although in a highly parametrized fashion. The key meteorological processes that can be treated are 1) nonsteady and nonhomogeneous along-valley winds and turbulent diffusivities, 2) convective boundary layer growth and inversion descent following sunrise, 3) cross-valley circulations, tributary flows and subsidence, and 4) interactions with above-ridgetop winds. The model is applicable under relatively cloud-free, undisturbed synoptic conditions and is configured to operate through at least one diurnal cycle for a single valley. The inputs required are the valley physical characteristics, the release rate as a function of time and space, the along-valley wind speed as a function of time and space, temperature inversion characteristics at sunrise, and sensible heat flux as a function of time following sunrise. Default values are provided for certain inputs in the absence of detailed observations. The outputs are air concentrations and deposition fields as functions of time and space.

3.0 Meteorological Measurements to Support the Models

Following is a review of the meteorological data that are currently needed as inputs to the three models.

3.1 FSCBG Model

The following table provides a listing of the meteorological measurements needed to drive the FSCBG model, and the equipment that could be used to make the required measurements.

MEASUREMENTS NEEDED	POSSIBLE EQUIPMENT
Profile inputs	
temperature and relative humidity	tethersonde, airsonde, radiosonde, surface measurements and log extrapolation
wind direction and speed	tethersonde, tracked airsonde, rawinsonde, Doppler sodar, surface measurements and log extrapolation
mixing depth	from equipment above
Single inputs	
net radiation	net radiometer, pyranometer
cloud cover	airways observations, net radiometer, pyranometer
pressure	pressure sensor, barograph
wind direction standard deviation	wind set
Miscellaneous inputs	
global radiation (direct + diffuse)	pyranometer

Table Notes:

- Radar profiler/RASS (Radar Acoustic Sounding System) could measure wind and temperature profiles continuously, but is blind for the first 150 m of elevation and is expensive. RASS provides temperature soundings to heights of about 600-800 m, with limited height resolution.

- Doppler sodars and tethersondes often cannot sound deeply enough to measure mixing depth during summer. Also, many current sodars do not provide information at low enough heights to be of use in meteorological monitoring of aerial spray operations. Mini-sodars are available, however, that can measure winds through depths of 100m with resolution of approximarely 10m. Tethersondes cannot be used in strong winds.

- Net radiometers with rigid domes would be preferable the the ones that have to be inflated with dry nitrogen.

- Cloud cover observations are available from some airports during hours of operation and from certain National Weather Service and Federal Aviation Administration facilities. Net radiometers/pyranometers or on-site cloud observations are possible backups.

- Silicon cell pyranometers are recommended, as they are inexpensive and require little maintenance.

Discussion:

The profile inputs for FSCBG are somewhat simpler than might be implied by the table entries. The model converts the temperature and relative humidity profile data to two constant values, one above and one below the canopy. Only two values are really necessary, one just below the canopy top and one at aircraft height. The model also cannot use more than one wind direction and it uses the wind direction from the highest elevation reported. The height of the aircraft would probably be the most appropriate level. Furthermore, the model is insensitive to actual mixing layer depth so long as it is greater than several hundred meters and the spray is released near the top of the canopy. The mixing layer depth therefore needs to be measured only during the morning transition period. On the other hand, the morning transition period is the preferred time for most forest aerial spraying operations.

The model is sensitive to pressure, so that pressure data are required. The net radiation measurements should ideally be made over the forest canopy, as they are used to estimate atmospheric stability and must take account of cloudiness.

Net radiation measurements taken within the canopy are generally not representative of the above-canopy radiation. In the absence of a net radiometer, an inexpensive pyranometer could be used for this purpose, as methods are available to estimate net radiation from measurements of incoming solar radiation.

A wind profile is needed from the ground to the aircraft altitude (i.e., 0 to 50-100 m above the canopy). Ascending non-tethered sondes rise too quickly through this shallow layer and sample only a near-instantaneous wind speed profile. The desired sounding is a mean wind speed profile.

3.2 AGDISP Model

The only additional input parameter required by the AGDISP model is the Richardson number. This can be determined from the same wind and temperature profiles specified for FSCBG.

3.3 VALDRIFT Model

The VALDRIFT model is a spray drift model for use in well-defined valleys on relatively undisturbed days when winds within the valley are locally driven. It requires wind data from one or more sites within the valley as a function of time. Either surface or vertical wind profile data can be assimilated into the model, as available. The model also uses a pre-sunrise temperature sounding, if available, through the valley depth, and an estimate of the fraction of incoming solar radiation that will be converted to sensible heat flux (i.e., a parameterized surface energy budget). It also needs surface temperature and pressure data. The wind and temperature profiles and other data are already specified for FSCBG, except for the surface energy budget fraction. Since VALDRIFT is a spray drift model and makes calculations far downwind of the spray block, the model calculations benefit greatly from additional wind measurement sites along the drift path, especially vertical wind profile data.

4.0 SEVERAL SPRAYING SCENARIOS

Several types of spraying application experiments could be conducted. Since the meteorological data necessary to support an experiment depends strongly on the experiment design we will illustrate the choice of meteorological measurements for three spray scenarios. The scenarios are chosen to represent three differing scales of experiments needing increasing levels of meteorological support.

For all three scenarios it is assumed that basic weather forecasting support would come from the closest National Weather Service Forecast Office, and that

+ on-site meteorological support should be focused on assisting the on-site manager to make informed application decisions in real time,

+ the on-site data set should be sufficient to document the occurrence/non- occurrence of pesticide deposition in the forest canopy to verify that the spray block was sprayed as desired, and

+ the on-site data set should be sufficient to document the occurrence/non- occurrence of pesticide drift and information on the direction of drift.

4.1 Scenario 1 - A Small-Scale Pesticide Application in a Remote Area

A small-scale pesticide apllication in a remote area requires the smallest amount of meteorological support. The on-site meteorological equipment for this application should be lightweight, portable, battery-operated, easy to assemble and disassemble, and should use radio communications, so as to provide the on-site manager with real time data.

4.2 Scenario 2 – A Routine Pesticide Application in an Accessible Forested Area

A medium-scale pesticide appplication in a non-remote forested area with normal access requires intermediate levels of meteorological support. We will assume that the spray block is accessible and consider the possibiity of using meteorological support equipment that can run off 115 VAC power (either from standard line power or gasoline-powered generators), and that can be transmitted by phone or radio to a fixed or portable operations center for real time use by the operational manager. The meteorological equipment to be used should still be portable rather than fixed, but could be moved by truck - or by helicopter, if necessary.

4.3 Scenario 3 – A Pesticide Spray Experiment with Research Goals

This experiment might be focused on the evaluation of a specific aspect of one of the models, such as canopy penetration, pesticide drift, dispersion in the aircraft wake, effect of cross winds on deposition, etc. The meteorological support for such experiments would need to be designed on an individual experiment basis and the location of the experiment would likely be chosen to maximize access and provide the supporting infrastructure to obtain needed data with new research instruments. Such experiments are costly and opportunities for sharing the costs through collaboration with other agencies or organizations should be investigated, when possible.

5.0 SITING AND FREQUENCY CONSIDERATIONS

The proper siting of meteorological measurement equipment can be a difficult problem, but must be addressed if suitable meteorological data support is to be obtained. A meteorologist with experience in siting of field equipment should be involved in the experiment planning, if possible.

5.1 Sampling Frequency and Duration - General Considerations

Sampling frequency of meteorological parameters in a given monitoring program varies over a wide range depending on the objectives and available resources of the program. Atmospheric turbulence data are frequently collected at rates up to 100 Hz, while some upper air data are routinely collected only twice per day (i.e., .00002 Hz). Typical sampling frequencies for meteorological data in support of aerial spraying will usually fall somewhere between these two extremes with the design dictated by two basic considerations:

1) Low frequency information can be derived from high frequency information but high frequency information can only, at best, be approximated from low frequency information and often is not available at all.

2) The cost of instrumentation, data loggers, data processing and analyses increase with increasing sampling frequency.

The first factor would suggest that high frequency sampling is preferable but the second factor indicates that cost and logistics must also play a role.

The primary control on sampling rate is the data logger and associated storage device. Modern data logging equipment should be capable of almost any reasonable logging rate. Since 1980, commercially available logging rates have increased by at least three orders of magnitude. Where 10KHz analog to digital (A/D) conversion boards were considered fast in 1980, 1MHz is possible today. There are, however, still various constraints associated with data loggers. The total rate must be divided by the number of channels, so that a 100KHz data logger will sample at 1KHz per channel over 100 channels. There is often 'overhead' associated with storing data, so that the logger may be slowed further by data storage requirements, especially if it is operated near capacity. Perhaps the most common limitation encountered with modern systems is the size of the associated storage device. Even a 1 megabyte storage

device can only store 1000 seconds of data when data are sampled at 1KHz.

There are hundreds of companies that manufacture and/or develop data loggers. Data Translation, Inc. and Strawberry Tree, Inc. are examples of companies specializing in A/D boards. LabTech Notebook, Inc. is a software company that develops user friendly software interfaces for use with most A/D equipment. Campbell Scientific, Inc. is an example of a company that designs complete, integrated meteorological monitoring systems including dedicated data loggers, meteorological instrumentation, logging software and radio and telephone communications hardware.

The sampling rate should be selected after considering the response time of the sensor being sampled. The time response is defined as the time it takes for an instrument to achieve two-thirds of full response of a step change in the parameter being measured. For example, if the temperature instantly changed from 0 to 10 degrees C, the time response of a thermometer measuring the change would be the time required for the thermometer to reach 6.66 degrees C. If the sampling rate is higher than the instrument response time, instrument characteristics are being measured rather than atmospheric changes. However, considering 1) above, the atmospheric information can be recovered at frequencies lower than the instrument response.

The nature of the actual signal from the transducer is also a consideration in sampling design. For instance, a common method of measuring wind speed is to attach a magnet to a set of cups which spin at a speed proportional to the wind moving past them. As the magnet turns, an inducted voltage is measured, which changes sign relative to its position in the magnetic field. Thus, one cycle is produced for every turn of the anemometer cups. Typically this type of instrument will be associated with a counter that electronically stores one count for every cycle. The signal from the counter is effectively digital or increments in a discrete step. If the cups turn one revolution for every 6m of fluid passage and the wind is blowing at 1m/s, the counter will only increment once every 6 secs. If the counter is sampled at 10Hz, 60 samples will be collected without any new information.

Finally, the variability of the parameter being monitored and the physical question that is being addressed must be considered. A typical spray swath may take from 10 seconds to 10 minutes or longer to complete. Therefore, atmospheric information is desired that would allow you to distinguish changes occurring inside these time frames. Wind speed and

wind direction can vary significantly over a ten minute period. If coverage or efficacy is different over different areas of the spray block, it is useful to correlate the time of spraying over the different areas with the ambient conditions. If only one average number is available for the duration of the spray period, the time and magnitude of interperiod variation cannot be discerned (see 1) above). Also, in dispersion modeling, the variance of wind speed and direction in particular (and the other measured parameters to a lesser degree) are often of fundamental significance. Due to statistical considerations which are beyond the scope of this document (see Priestly, 1983 for a complete discussion), the variance is more accurately discerned when calculated from higher frequency data.

Sampling duration is typically a straightforward problem. If the duration of spraying on a given day is anticipated to last 5 hours, it is useful to sample for two hours before and 1 hour or so after spraying stops to have a record in case precedent or antecedent conditions influence the program. Duration multiplied by sampling frequency summed over all the sampling channels will determine the size of the data set being stored and should be calculated beforehand to guarantee that sufficient storage is available. Storage capacity is typically expressed in bytes, so a knowledge of the number of bytes involved in individual data parcels allows an exact calculation of storage needs. (Occasionally, storage capacity will be stated in either bits or words. For a discussion of these terms, see .) There are scientific questions about such things as persistence in the environment or recirculation of aerially released material in the atmosphere which may require an alternate basis for the determination of sampling duration.

5.2 Guidance on Sampling Frequencies

The following section is intended as guidance to managers when designing meteorological monitoring for aerial spray operations. Meteorological researchers will obviously be guided by the considerations indicated above as well as their own experience, equipment and objectives. The section is intended to give order of magnitude sampling rates for typical equipment encountered in this type of monitoring.

20 Hz - Most commonly used for high frequency turbulence and turbulent flux sensors (more typical of research applications) such as sonic anemometers, hot-wire anemometers, single-turn thermocouples, etc. Sampling at these relatively high frequencies typically requires detailed knowledge of the instrument system from the sensors themselves through the logging and storage devices.

1 Hz - Most commonly used for cup anemometers and directional vanes. Note that 1 Hz sampling allows adequate variance measurements in these applications but still may exceed (higher frequency than) the time constants of common cup and vane anemometers. This sampling rate is sufficient to provide data for detailed meteorological analyses, but may not be necessary in a strictly operational environment.

0.1 Hz - Usually used for net radiometers, thermistors, and relative humidity sensors. Generally, the design and the data requirements from these sensors make higher frequency sampling unnecessary.

>.01 Hz - Most upper air measurements are done at lower frequencies. Pressure has typically been considered a low frequency measurement, though recent technological advances now allow higher frequency measurements when necessary.

5.3 Siting

Siting considerations are generally and instrumentation specific. The following section gives general measurement specific siting criteria.

Wind speed/Wind direction - The primary consideration in siting wind instruments is to sample the flow that will meet operational objectives. General siting guidelines are that obstacles will affect the flow for approximately 2 obstacle height (i.e. '2*H') upwind, 10 obstacle heights downwind and 2 obstacle heights upward. If the flow beyond the influence of obstacles is desired these criteria should be kept in mind. Many times, however, the flow in or near vegetation is of interest since vegetative surfaces are often the target in aerial application operations. Anemometers can be sited in canopies but dense or non-representative obstacles should be avoided, direct obstruction by obstacles such as branches is obviously unacceptable but may not be apparent until the canopy is disturbed at some higher wind speed. Instrument height is a difficult question to answer in generic terms. The wind will increase in velocity logarithmically with height above a solid surface. Since the change is greater near the surface, instrument spacing should be vertically smaller near the surface. However, in forest canopies vertical spacing is a difficult question. Generally, many tree species exhibit less dense foliage in the trunk space and a foliage maximum somewhere in the upper canopy. If resources exist, these layers should be monitored since they exhibit different flow characteristics. In an operational program, it might be useful to take one measurement in a free flow away from obstacles and another at an in-canopy height that corresponds to the in-canopy

target or ecological niche of the pest.

Temperature - Siting considerations for thermometry are similiar to those for anemometry with the important exceptions that thermometers have no moving parts, and they are susceptible to errors due to the thermodynamics of the instrument and the instrument mounting. Thermometers need to be shielded from direct solar radiation and isolated from surfaces or other heat sources which can conduct heat to the thermometer. It is general practice to collocate the thermometer with the wind instruments. Thermometers are often aspirated to avoid local heat build-up although it should be realized that the measured temperature is then an integration of the air volume being moved across the sensor.

Humidity - Humidity sensors should be sited in a representative location away from local moisture sources and shielded from solar radiation which can cause excessive drying through surface heating. Humidity sensors are also often aspirated to avoid local boundary layer effects on the sensor.

Radiometers - In most cases, radiometers are sited to obtain the maximum unobstructed view of the sky, although occasionally researchers position net radiometers in the canopy to measure the local energy budget. Since net radiometers view both upwards and downwards, it is important to site the net radiometer over a representative surface considering color, roughness and moisture.

Upper Air Measurements - Upper air measurements should be made so that they are representative of the source or of the atmosphere where drift is occurring.

Pressure - The exposure of a pressure sensor is generally not critical, although the pressure sensor should be kept in an environment where temperature does not vary excessively and where insects do not obstruct the pressure port. Pressure sensors must be calibrated occasionally in order to have useful accuracies. For most purposes, accuracies within 1 or 2 mb are sufficient.

6.0 FUTURE TECHNOLOGY CHANGES

It is difficult to predict the impact of future technological developments on the state of FS aerial spraying activities. However, there are some technologies which exist and would provide valuable information but for various reasons (typically cost and ease of use) are not yet used operationally in spray operations. The two primary areas which will be focused on here are:

1) Remote sensing technology which would allow more detailed information of meteorological parameters near the spray cloud as well as direct information regarding the cloud itself.

2) GPS technology which will allow more accurate positioning of all aspects of the spray operation.

6.1 Remote Sensing Technology

6.1.1 SoDAR

Sound Distance and Ranging (SoDAR) technology can be used to describe the wind field above the forest canopy in the vicinity of spray aircraft. This technology utilizes the temperature structure in the atmosphere to produce a sonic echo. The frequency of this echo is shifted proportional to the speed of the fluid producing the return. This instrumentation yields wind speed and direction information. Preliminary tests indicate that this is potentially very useful technology but standard commercial instrumentation does not yield data in the lowest levels (<30m) of the atmosphere of most interest in aerial spraying applications. This does not appear to be a fundamental limitation of the technique and the state of this technology is certainly worth monitoring. The SoDAR technology is becoming easier to use as time goes on but is still expensive (30-70K per unit). Although not yet available commercially, some organizations have built mini-sodars that are capable of good vertical resolution near the ground but with reduced height range. Such instruments typically reach heights of 100 to 200m with 10m resolution.

6.1.2 LiDAR

Light Distance and Ranging (LiDAR) technology can be used to describe the wind field at height and in monitoring of the actual position of spray material as it disperses after release. The LiDAR relies on light which is backscattered from atmospheric particulates. The motion of the scattering particles causes a frequency shift in the backscattered light which is proportional particle velocity. This

technology can also be used to perform direct tracking of the spray material as long as the material is at concentrations in the atmosphere which exceed background particulate levels. Other approaches using reflective tracers and chemical signatures may be possible to gather information on spray material at concentrations below that of background particulate.

There are a number of problems with the technology as it currently exists from an operational standpoint. The backscattered signal provides a qualitative picture of the spray material which provides relative information but is hard to quantify. The light beam is attenuated, in other words, if it is backscattered by a particle, no information can be gained about material behind that particle. Currently, this technology is both expensive (>60K) and it is not eye-safe, requiring operating and nearby personnel to wear safety goggles. This technology has substantial potential in aerial spray monitoring as these problems are solved.

6.1.3 GPS

Global Positioning Satellite systems (GPS) use signals transmitted from a constellation of polar orbiting Earth satellites to determine position on the surface of the Earth. The satellite constellation is owned by the U.S. Department of Defense (D.O.D.) and the satellite signal is systematically scrambled for national security reasons. However, this intentional accuracy degradation can be overcome by fixing the location of a point on the ground exactly. This point is then used to determine the degree and nature of the degradation and a decoded signal can be obtained. The positional accuracy available using this 'differential' signal is within 2m of actual position. This is approximately two orders of magnitude better than accuracies available with previous systems and positional updates can be obtained at high frequencies making the technology suitable for aircraft navigation.

This technology has many important applications to aerial spraying of pesticides. The most important application with regard to the modeling of spray drift is that the location of the source can be exactly determined as well as the positions of the monitoring stations. The concentration and depostion fields of the released material are very sensitive to source position, especially in the near field. This technology is now becoming more widely available, as the cost of GPS receivers comes down.

6.1.4 Other Remote Sensing Technologies

There are other technologies which are currently considered research tools but will impact the discipline by

improving the basic understanding of spray drift. Among these are sounders using various frequencies and modulation of radio waves. Perhaps the most important of these tools is the Radio Acoustic Sounding System (RASS). This is an important tool because it allows the remote sensing of temperature as well as wind speed and velocity. This temperature profiling capability would allow information to be gathered regarding atmospheric stability that would influence dispersion of the spray material. Other remote technology includes thermal infrared photography. This technique may prove useful for sensing spray material but is not yet widely used. It has the potential for wide spread use because it is relatively inexpensive. In general, this field is expanding rapidly as technology that was developed in defense programs is now being moved into the civilian sector.

7.0 Conclusions and Recommendations

This report has specified the meteorological measurements necessary to use the USDA Forest Service FSCBG complex of models (FSCBG, AGDISP and VALDRIFT) to simulate or predict spray drift. The report offers both the minimum monitoring requirements and suggestions for expanded programs which will improve model reality and, therefore, model accuracy. The report also endeavors to make readers aware of new meteorological monitoring technology which will impact understanding of spray drift in general and allow a more detailed understanding of future spray events. This new technology will feed back to future model development activities.

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Appendix E

List of Committee Members

Committee Members September 1994

National Spray Model and Application Technology Steering Committee

Linda Abbott (APHIS)
USDA/APHIS/BBEP/EAD
6505 Belcrest Rd., Rm 543
Hyattsville, MD 20782
PH (301) 436-5170
FAX (301) 436-3368

Larry Barber
USDA Forest Service
Forest Pest Management
P.O. Box 2680
Asheville, NC 28802
DG L.Barber:S29A
PH (704) 257-4323
FAX (704) 257-4840

John (Jack) W. Barry
USDA Forest Service
Forest Pest Management
2121-C 2nd Street
Davis, CA 95616
DG J.Barry:R05H
PH (916) 758-4600
FAX (916) 757-8383

Terry Biery
910 AG/DOS
3976 King Graves Rd.
Youngstown-Warren RGN APRT
ARS OH 44473-0910
PH (216) 392-1178
FAX (216) 392-1156

Sandy Bird
US Environmental Protection Agency
Environmental Research Lab.
College Station Road
Athens, GA 30613
PH (704) 546-3160
FAX (706) 546-3340

Fred Bouse
USDA, Agricultural Research Service
Southern Crops Research Laboratory
Aerial Application Research Unit
231 Scoates Hall TAMU
College Station, TX 77843-2122
PH (409) 260-9364
FAX (409) 260-9367

Parshall Bush
Ag Ser Lab
110 Riverbend Rd
Athens, GA 30605
PH (706) 542-9023
FAX (706) 542-1474

Erroll Caldwell
Forest Pest Institute
P.O. Box 490
Sault Ste. Marie, Ontario
CANADA P6A 5M7
PH (705) 959-9461
FAX (705) 759-5700

Scott Cameron
Texas Forest Service
Cudillit Forestry Center
P.O. Box 310
Lufkin, TX 75902
PH (409) 639-8185
FAX (409) 845-5764

Dave Esterly
DuPont Agricultural Products
Experimental Station
Wilmington, DE 19880-0402
PH (302) 695-1690
FAX (302) 366-5467

Bruce Grim
Commander
Dugway Proving Ground
ATTN: STEDP-JCT (Bruce Grim)
Dugway, UT 84022
PH (801) 831-3371
FAX (801) 831-2397

Jim Hadfield
USDA Forest Service
Eastern Washington Forest Health Office
Forest Sciences Laboratory
1133 N. Western Ave
Wenatchee, WA 98801
PH (509) 664-2777
FAX (509) 664-2701

Kevin Howard
USDA-ARS
P.O. Box 36
Stoneville, MS 38776
PH (601) 686-5240
FAX (601) 686-5422

Ellis Huddleston
Dept. of Entomology, Pathology
and Weed Science
Box 3BE
New Mexico State Univ.
Las Cruces, NM 88003
PH (505) 646-3934
FAX (505) 646-5975

I. W. (Buddy) Kirk
USDA-ARS
231 Scoates Hall TAMU
College Station, TX 77843-2122
PH (409) 260-9364
FAX (409) 260-9367

Steve Knight (APHIS)
USDA/APHIS/PPQ
6505 Belcrest Rd. (FB - Room 816
Hyattsville, MD 20782
PH (301) 436-8716
FAX (301) 436-5816

Alex Mangini
USDA Forest Service
Forest Pest Management
2500 Shreveport Highway
Pineville, LA 71360
DG A.Mangini:R08F06A
PH (318) 473-7286
FAX (318) 473-7117

Mike McManus
USDA Forest Service
Center for Biological Control
of NW Forest Insects & Diseases
51 Mill Pond Road
Handen, CT 06514
DG M.McManus:S24L07A
PH (203) 773-2027
FAX (203) 773-2183

Robert E. Mickle
Air Quality Process Research Division
Atmospheric Environment Services
4905 Dufferin Street
Downsview, Ontario
Canada M3H 5T4
PH (416) 739-4851
FAX (416) 739-4224

Karl Mierzejewski
Pennsylvania State Univ.
Department of Entomology
Pesticide Lab
University Park, PA 16802
PH (814) 863-4439
FAX (814) 865-1021

David R. Miller
Univ. of Connecticut
308 W.B. Young Building
1376 Storrs Road
Storrs, CT 06268
PH (203) 486-2840
FAX (203) 486-2504

C. S. Parkin
Cranfield University
Silsoe College, Silsoe
Bedford MK 45 4DT
United Kingdom
PH +44 (0) 528 860428
FAX +44 (0) 525 861527

Jim Rafferty
U.S. Army Dugway Proving Ground
Attn: STEDP-MT-M
       (Jim Rafferty)
Dugway, UT 84022
PH (801) 831-5101
FAX (801) 831-5289

John Ray
Forest Research Institute
Private Bag 3020
Rotorua, New Zealand 82179
PH 011 6473 475516
FAX 011 6473 479380

Dick Reardon
USDA Forest Service
Forest Pest Management
180 Canfield Street
Morgantown, WV 26505
DG R.Reardon:S24L08A
PH (304) 285-1563
FAX (304) 559-7041

Brian Richardson
Forest Research Institute
Private Bag 3020
Rotorua, New Zealand 82179
PH 011 6473 475516
FAX 011 6473 479380

Dave Rising
USDA Forest Service
Equipment Development Center
Fort Missoula - Building #1
Missoula, MT 59801
DG D.Rising:R01A
PH (406) 329-3900
FAX (406) 329-3719

Tim Roland
USDA APHIS, PPQ
Aircraft Operational
Rt. 3 Box 1001
Edinburg, TX 78539
PH (210) 580-7388
FAX (210) 580-7389

Bob Sanderson
Dept. of Entomology
New Mexico State Univ.
Box 30003/Dept. 3BE
Las Cruces, NM 88003-0003
PH (505) 646-3543
FAX (505) 646-5975

Pat Skyler
USDA Forest Service
Forest Pest Management
2121-C 2nd Street
Davis, CA 95616
DG P.Skyler:R05H
PH (916) 758-4600
FAX (916) 757-8383

Dave Smith
Dept. of AG & Biological Engineering
P.O. Box 5465
Mississippi State Univ.
Mississippi, 39762
PH (601) 325-3282
FAX (601) 325-3853

Doug Sommerville
US Army ERDEC
ATTN: SCPRD-RTC
Bldg. 3160
Aberdeen, MD 21010
PH (301) 671-4348
FAX (304) 285-1505

Bill Steinke
Biological & Agricultural
Engineering Extension
University of California
Davis, CA 95616-5294
PH (916) 752-1613
FAX (916) 752-2640

Milt Teske
Continuum Dynamics,Inc.
P.O. Box 3073
Princeton, N.J. 08543
PH (609) 734-9282
FAX (609) 734-9286

Harold Thistle
Missoula Technical Development Center
Ft. Missoula - Bldg. 1
Missoula, MT 59801
DG H.Thistle:R01A
PH (406) 329-3900
FAX (406) 329-3719

Dave Valcore
DowElanco
9410 Zionsville Rd.
S. Campus Bldg. 304
Indianapolis, IN 46268
PH (317) 337-7933
FAX (317) 337-7922

Dave Whiteman
Battelle Pacific North West Lab.
Battelle Blvd.
P.O. Box 999
Richland, WA 99352
PH (509) 376-7859
FAX (509) 376-5217

Jeff Witcosky
USDA Forest Service
George Washington National Forest
P.O. Box 233
Harrison Plaza
Harrisonburg, VA 22801
DG J.Witcosky:R08F08A
PH (703) 564-8387
FAX (703) 564-8393

Al Womac
Ag. Eng. Dept.
Univ. of Tennessee
P.O. Box 1071
Knoxville, TN 37901-1071
PH (615) 974-7266
FAX (615) 974-4514

Nicholas Woods
Univ. of Gueensland
C-PAS, Gatton College
LAWES, QAD, 4343
Australia
PH +61 74 601293
FAX +61 74 601283